PROCEEDINGS OF A
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The Control of Exposure of the Public to Ionizing Radiation in the Event of Accident or Attack

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THE CONTROL OF EXPOSURE OF THE PUBLIC TO IONIZING RADIATION IN THE EVENT OF ACCIDENT OR ATTACK

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TOPIC 1 SESSION A

The Effects of Dose, Dose Rate, and Depth Dose Upon Radiation Mortality

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There are three objectives in this paper. First is an illustration of the lethal syndromes induced by whole body irradiation. Second is the demonstration of the effect of depth dose curves on mortality including neutron depth dose curves measured in Nevada from a nuclear bomb explosion. Third is the effect of dose rate on repair of radiation injury.

Symptomatology Induced by Whole Body Irradiation

The symptomatology induced by whole body irradiation varies with dose and time after irradiation. After very high doses of radiation, on the order of many thousands of rads (> 2000) exposure, in a short period of time, the predominant symptomatology is related to injury of the nervous system with ataxia, convulsions, coma and early death. At a lower range of radiation of several hundred to a few thousand rads (600–2000), the predominant symptomatology is related to injury to the gastrointestinal tract with nausea, vomiting, diarrhea, dehydration, and death. At lower doses of radiation on the order of a few hundred rads (200–600), the symptomatology observed is related to 1) depression of blood cell formation, primarily hemorrhage from a deficiency of platelets, 2) infection as a result of deficiency of granulocytes required to fight infection, and 3) anemia, a result of hemorrhage and the cessation of blood cell production. There is considerable overlapping of these three syndromes. The one that we are concerned with, in the 50% lethal dose range of radiation (LD_{50}), is the hematological syndrome. In this syndrome, there will be, to a certain extent, gastrointestinal symptomatology in the early days from which individuals usually survive to experience the hemopoietic syndrome.

Estimation of Human LD_{50} Dose of Radiation

Before one can consider the effects of radiation on man it is necessary to have some appreciation of the dose of radiation that is supralethal, will kill a graded fraction of people, and an approximation of the maximum sublethal dose of radiation. An approach to this problem was presented some years ago by Cronkite and Bond [1]. Data from exposure of dogs, Japanese atomic bomb casualties, and from Marshallese exposed to fallout radiation led to a relatively low air dose of radiation (350 rad) for the 50% lethal dose ($LD_{50/60}$), the dose that will kill 50% of exposed people in a 60-day period if given no therapy.

Jacobs *et al.* observed a good correlation between depression in the granulocyte count in the blood of Japanese atomic bomb casualties and mortality [2]. Similar observations were made on dogs exposed to nuclear bomb gamma rays. Marshallese exposed to 175 rad in air fallout gamma radiation had a moderate depression in granulocyte and platelet counts but there were no bacterial infections, thrombopenic bleeding or mortality. They received no specific therapy such as antibiotics or blood transfusions. It is believed that an additional 50–75 rads would have placed them in the low lethal dose range in the vicinity of 225–250 rads. In Figure 1, likely and unlikely human LD_{50} curves are plotted. The low lethal point is anchored at 250 rads in air for a fallout field. Most large animal lethal dose curves are relatively parallel. One can then draw a curve parallel to the dog LD_{50} curve as seen in Figure 1. The LD_{50} is about 350 rads in air for a fallout gamma field and 100% mortality around 500 rads where it is believed few if any human beings would survive unless given extensive antibiotics, transfusion therapy, and/or bone marrow transfusions. The latter are impractical in the presence of mass casualties. The above approach admittedly is a best "guesstimate" of air dose LD_{50} for man from a planar source as in a semi-infinite fallout field.

The Effect of Energy of Radiation on Depth Dose Curves

The distribution of dose throughout tissue varies considerably with the energy of radiation and with the

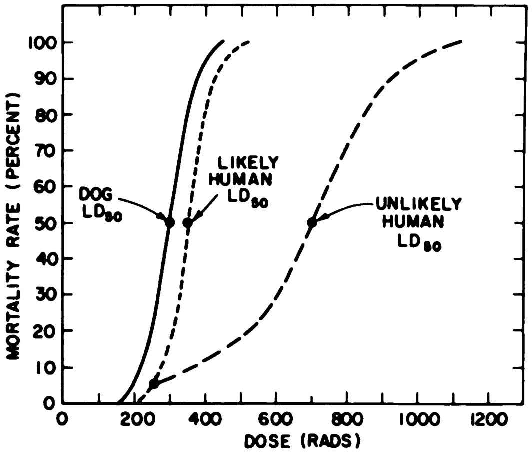

Fig. 1 Schematic presentation of likely and unlikely $LD_{50}/_{60}$ curves for radiation mortality in man. From Cronkite and Bond [1].

geometry of exposure. The influence of energy is illustrated in Figure 2 and is taken from Bond *et al.* [3].

Figure 2 shows a series of depth-dose curves. Curve (a) is 250 kVp x ray. From the scatter of the radiation, one has an actual buildup in the first few centimeters of tissue and then a very sharp drop-off so that the exit dose is approximately 15% of the air entrance dose. With 2000 kVp x ray, curve (b), there is a slight buildup in the first two or three centimeters of tissue and then a diminution so that the exit dose is approximately 30% of the entrance air dose. Curve (c), which are actual measurements made in nuclear bomb tests in Nevada, shows much less falloff in the prompt gamma radiation from the nuclear bomb and a very slight buildup in the first couple of centimeters. Curve (d) shows the curve for cobalt-60. One can see that there is a considerable difference in the deposition of energy in unit density material, or tissue equivalent material, as a function of the depth in the tissue. Since the target cells for the hematopoietic syndrome are the stem cells for perpetuation of hematopoiesis, it is really the dose to these cells that is important. They are distributed widely throughout the bone marrow and only under certain circumstances will there be a uniform dose to all target cells.

The Effect of Geometry of Exposure upon Depth Dose

The effect of geometry of exposure is shown in Figure 3. In this figure the dose is expressed as percent of surface dose. With unilateral exposure the exit dose is 46% of the entrance surface dose. Note that the air dose is about 85% of the surface dose because of backscatter increasing the surface dose. When one-half of the total dose is delivered to opposite sides of the phantom, the surface dose from each side is obviously 50%. When exposed on the other side one adds for each depth the dose from the opposite exposure obtaining a relatively uniform depth dose curve of about 73% of the surface unilateral exposure dose.

The Effect of Geometry of Exposure upon Mortality

This subject was studied years ago in the context of laboratory and field atomic bomb exposures of swine to high energy x ray and to atomic bomb gamma radiation by Tullis *et al.* [4, 5]. In civil defense planning one is concerned mainly with fallout. Unfortunately, there are no large animal studies on the effect of bomb neutrons or fallout gamma radiation on mortality in large animals.

Tullis *et al.* published data on determination of the LD_{50} in swine and these are shown in Figure 4 [4, 5]. The doses are expressed as R in air. Unilateral 2000 kVp x rays yielded an LD_{50} of 400 R in air. Bilateral 2000 kVp x rays produced an LD_{50} of 400 R in air. The LD_{50} from initial bomb gamma radiation expressed as R in air was 230 R. These air doses when converted to midline tissue doses on the basis of the comparative depth dose curves in Bond *et al.* are 300 R, 220 R, and 184 R [3]. These differences are in part explained by there being essentially no inverse square effect with bomb gamma since the distances from the source are great. In the case of unilateral radiation, the tissues distal from the midpoint receive much less radiation, thus fewer hemopoietic stem cells critical for survival are killed.

In real life situations air doses or dose rates are made available by instruments or dosimeters and these are what must be used.

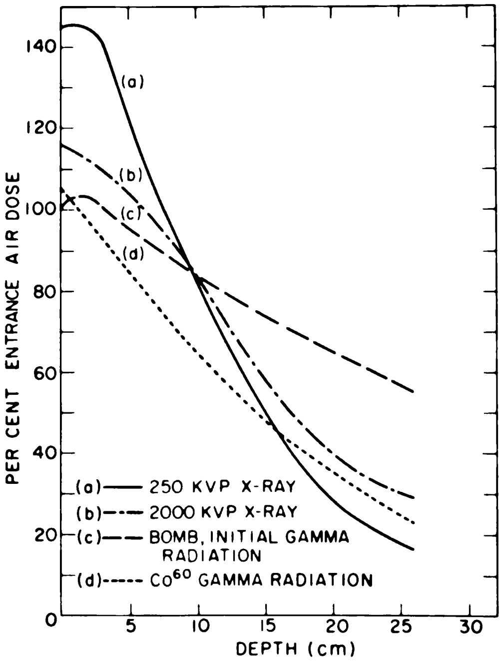

Fig. 2 Depth dose curves for different energies of radiation in tissue equivalent phantoms. From Bond *et al.* [3]

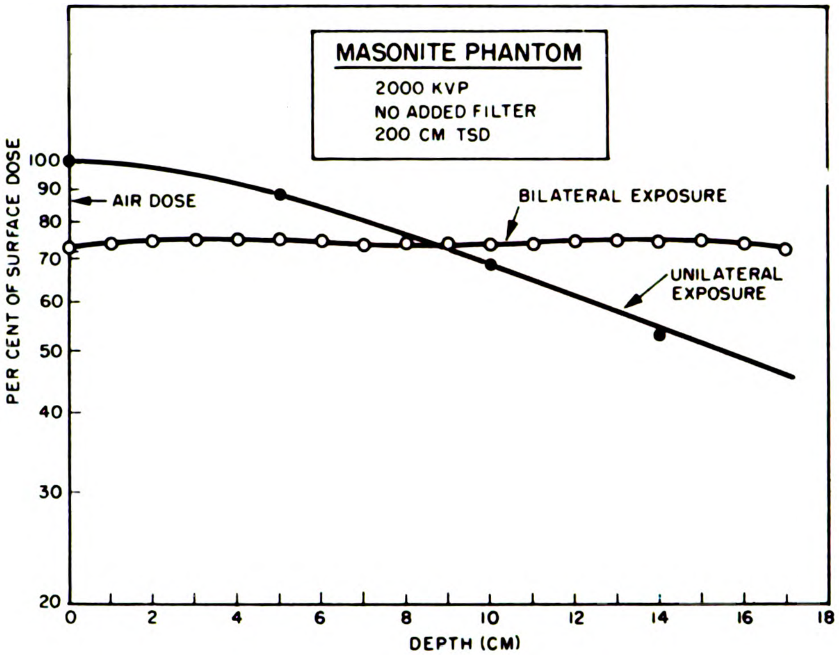

Fig. 3 The influence of geometry of exposure upon depth dose curves comparing unilateral to bilateral exposure. From Bond *et al.* [3]

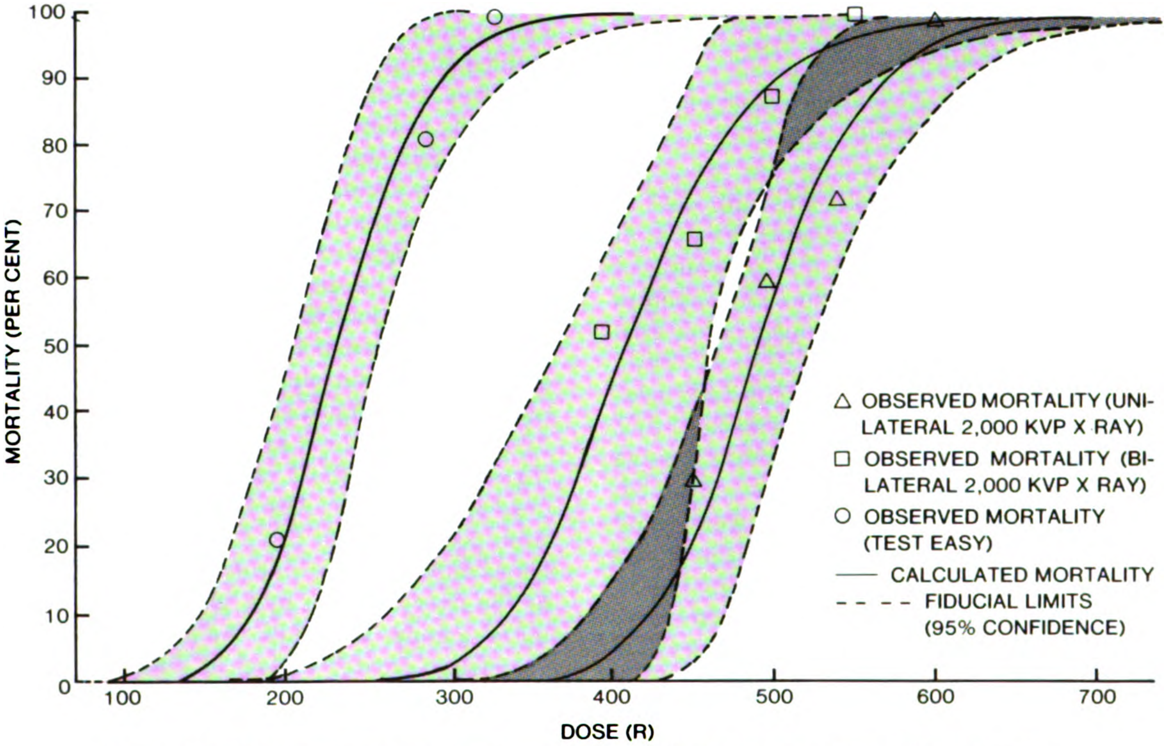

Fig. 4 The effect of exposure geometry on mortality of radiation in swine. From Tullis *et al.* [4, 5]

Neutron Depth Dose Curve from an Atomic Bomb

The neutron depth dose curve from an atomic bomb air explosion in Nevada is shown in Figure 5, and is from Bond *et al.* [6]. Threshold dosimeters for various energy neutrons were used to get an approximation of the energy spectrum (Au, ^{239}Pu, Np and S). The dosimeters were immersed in a solution of sucrose and urea that mimics the chemical composition of human tissue. In Figure 5 note that the incident tissue dose is 75% of the air dose in absence of the phantom. The dose falls off with depth in the tissue equivalent material to about 15% of the incident air dose at 17 cm

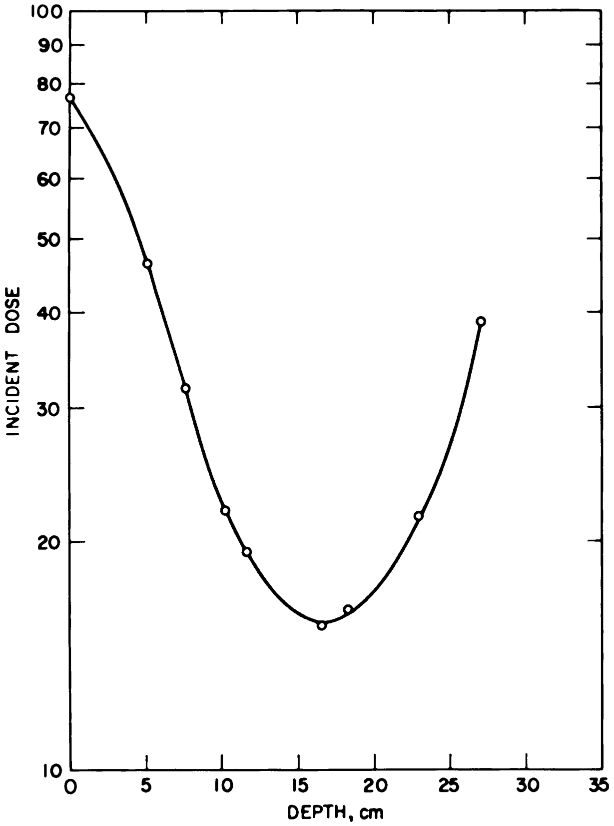

Fig. 5 Fast atomic bomb neutron depth dose curve in tissue equivalent solution. From Bond *et al.* [6]

and then increases to 40% of the incident air dose at the exit. The buildup between 17 cm and the exit at 27 cm and the shape of the curve show that the source of neutrons is scattering from air back into the phantom and that the neutron dose in tissue equivalent material is rapidly attenuated.

From this depth dose curve it is difficult to "guesstimate" the probable LD_{50} for man. The fall-off is about what one would expect with 100 kVp x rays so far as the descending part of the curve is concerned. The increasing dose towards the backside would tend to increase the kill of hematopoietic stem cells in that region compared to midline killing of hemopoietic stem cells. The maximum relative biological effectiveness of fast neutrons for killing hematopoietic stem cells is about 2. The survival curve for hemopoietic stem cells is known. In principle, one could calculate the incident neutron dose required for killing the same fraction of stem cells as with the gamma depth dose curve that yields an estimated human LD_{50} of 350 rads air dose. This has yet to be done.

Fallout Gamma Depth Dose Curve

Fallout radiation is a major problem for civil defense planning. There is some human experience with accidental exposure of people to fallout as a result of the accident on 1 March 1954 that exposed Marshallese, American servicemen, and Japanese fishermen to fallout radiation [7]. The fallout material stuck to trees, Marshallese houses, the ground, and on the people themselves. The gamma radiation comes from all directions from the semi-infinite planar source of the fallout field. The beta component may produce beta burns that could be portals of entry for infection if there is sufficient gamma exposure to produce a marked depression in the granulocyte count. Many features about the accident were unique. Individuals were lightly clothed. It was in the humid tropics. Fission products were attached to calcium oxide, or slaked lime, produced by the incinerated coral, and particles stuck to the exposed skin and to the clothes. Such conditions probably would not prevail in the continental U.S. See reference 7 for details.

The fallout arrived approximately 4 to 5 hours after the detonation. The evacuation was at 51 hours after the detonation. During a 48-hour period, there was an accumulation of approximately 175 rads in air to these people. The dose rate at the beginning was greater than it was at the time of evacuation, falling off by $t^{-1.2}$. The average dose rate was about 3.7 R per hour.

The energy distribution of the source fallout material is described in reference 7. The energy in keV varies from a few keV up to about 1700 keV. The gamma energies lower than 80 keV will be very poorly absorbed, resulting in a higher dose to the surface of the body; radiation from source material with greater keV will be highly penetrating as shown on the depth-dose curves presented earlier. The combination of the bath of beta particles and the wide energy spectrum results in a high surface dose of radiation. For example, in Figure 6, the depth dose curves for initial bomb gamma radiation and a residual field of fallout in Nevada are plotted. The measurements were made by Sievert ionization chambers implanted in Masonite phantoms [7]. The doses are plotted as percent of the 3 cm dose. Note the sharp increase in the dose between the surface and the 3 cm point to 8 times the 3 cm dose at the surface. Also note the very flat depth dose from 3 cm beneath the surface on one side to 3 cm beneath the surface on the other side. Thus, in terms of the dose at 3 cm in a phantom from fallout and initial gamma radiation, the fallout field will have a somewhat greater biological effect in killing hemopoietic stem cells and thus on mortality.

A problem arises in measurement of dose rates from fallout fields. If the energy cut-off of the instrument is too low, the effective dose in air would result in predicting a biological effect greater than in fact would happen. The Sievert ionization chambers being very small and implanted in the Masonite (tissue equivalent) phantoms measure the dose delivered to successive depths in tissue. It is suggested that the radiation dose rate dosimeters should have an appropriate cut-off so that they will correspond to the dose rate at about 2–3 cm in tissue equivalent materials. Whether this has been considered is not known to this author

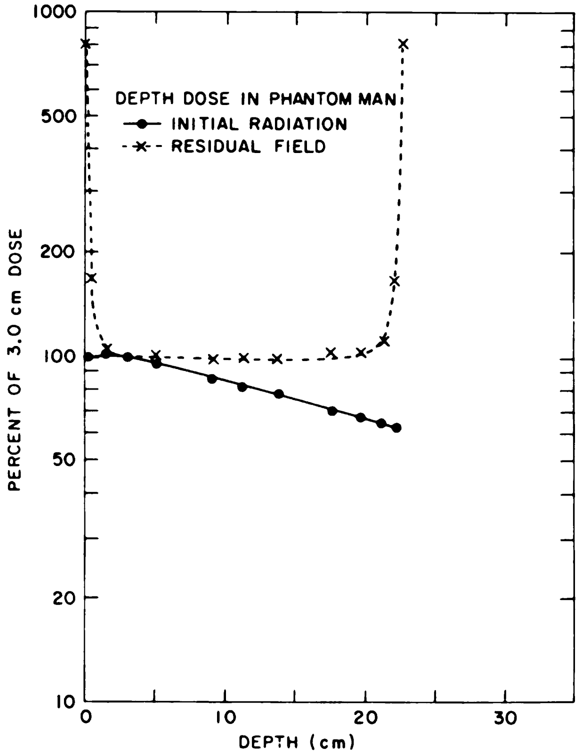

Fig. 6 Comparison of depth dose curves from initial bomb gamma radiation and from a fallout field in Nevada. From Cronkite, Bond, and Dunham [7]

nor is it clear to this author how one can convert a measured air dose rate to a meaningful midline tissue dose rate without more information than has been available to this author.

Dose Rate Effects on Mortality and Repair of Radiation Injury

Bateman, Bond, and Robertson analyzed mortality data in the literature and came to the conclusion that the 50% effective dose rate varied linearly with the reciprocal of the cube root of the radiation dose [8]. In general with dose rates greater than 1 rad per minute, the effectiveness per rad in killing increased; with dose rates less than 1 rad per minute the effectiveness per rad for killing diminished. At the U.S. Naval Radiological Defense Laboratory, studies on effect of varying dose rates on mortality in sheep and swine were carried out [9, 12]. Nachtwey, Ainsworth and Leong determined the single dose LD_{50} in swine [9]. At intervals after a single sublethal exposure to 240 or 265 R, they determined the LD_{50} in these swine. They concluded that by 3 days after exposure to the above sublethal doses, 51% of the injury had been repaired, by 7 days 65% of the initial injury, and by 20 days the swine appeared to be more radioresistant than nonexposed swine. These studies do not reflect chronic exposure but do demonstrate that radiation injury is repaired insofar as mortality response is concerned.

Hanks *et al.* exposed sheep to 165 R at dose rates of 0.5, 0.95, 1.85, and 3.90 R/hr [10]. The acute LD_{50} was determined immediately after the 165 R exposure by exposing sheep to graded doses of ^{60}Co gamma radiation at 10 R/min. The results are shown in Table I. Note that the negative values for residual injury after completion of 165 R at 0.5 and 0.95 R/hr implies increased radioresistance. At the higher dose rates, residual injury of 75 and 104 R remain. Roentgens repaired per hour vary from 0.58 at 0.50 R/hr exposure to 1.49 R/hr at an exposure rate of 3.9 R/hr. The repair per hour is greater at the higher dose rate but is still less than the dose rate so that injury accumulates at a greater rate than it is repaired.

Ainsworth *et al.* have studied the effect of continuous irradiation at different dose rates on mortality in sheep [11]. As the exposure rate is decreased from 670 R/hr to about 25 R/hr, the $LD_{50/60}$ increases linearly from about 230 R to 330 R. When the dose rate is dropped to 3.67 R/hr and 2.0 R/hr the $LD_{50/60}$ increases sharply to about 550 R and 630 R respectively. It is to be noted that exposure time increases as the dose rate decreases allowing more time for repair. From studies such as those described above, it is certain that in two large animal species, swine and sheep, the repair processes proceed in parallel with injury accumulation modifying the lethal effects of a given dose of radiation given continuously at dose rates less than 25 R per hour. Between 25 R/hr and 3.67 R/hr there is a sharp inflection in the curve and the LD_{50} climbs sharply between these two dose rates.

Actual exposures of human beings in fallout fields will not be at a constant rate since the fallout field will decay according to the $t^{-1.2}$ rule. In addition, it is assumed that individuals will be exposed intermittently as they emerge from sheltered positions to perform essential tasks. It is possible that repair will be more effective during intervals of no exposure or at lower dose rates as in sheltered positions. It is not possible with present animal data to extrapolate directly to man. There are not sufficient data for this extrapolation and, in any event, one does not know if man will respond quantitatively the same as sheep and swine respond in respect to repair of and accumulation of radiation injury. There is, however, no reason to believe that repair processes do not operate in man.

The Penalty Table in NCRP Report No. 42 for decision making in nuclear attacks [12] is one of the subjects that needs to be addressed. Is it useful? Should it be disregarded? Should it be revised? One can really not make a good value judgment on this issue. In summarizing my attitude towards the Penalty Table, I would recapitulate that the Marshallese received 175 rad in air over a 47-hour interval, average dose rate of 3.75 R/hour. Their hematopoietic suppression, in my opinion as a clinician, bordered on the development of infection, hemorrhage, anemia. This, admittedly, is an opinion. The Penalty Table states that an air dose of 450 R over one week, or 2.7 R per

Table I—*Injury repaired during exposure to 165 R at various dose rates. Hanks et al. [10]*

	Dose rate (R/hour)[a]			
	0.50	0.95	1.85	3.90
$LD_{50/60}$[b]	268(224–328)	279(244–323)	162(141–182)	133(106–162)
Residual injury at completion of protracted exposure (R)[c]	−31	−42	75	104
Roentgens repaired	196	207	90	61
Duration of protracted exposure (hours)	340	180	89	42
Roentgens repaired/hour	0.58	1.15	1.01	1.49

[a] Midline air dose rate.

[b] Determined within a few hours after completion of the protracted exposure.

[c] Calculated by comparing the $LD_{50/60}$ determined at the completion of the protracted exposure with the single acute exposure $LD_{50/60}$ of 237 R.

hour, will be an LD_{50} for man. The USNRDL data in respect to mortality suggests that one R per hour is repaired at dose rates of about 2 R per hour, or 360 rads being repaired, leaving a sublethal injury of 82 rads. The accidental chronic exposure of human beings to ^{60}Co gamma radiation suggests that the observed repair rates in sheep may apply to man [13]. In this case the Penalty Tables are far off mark.

It is to be noted, however, that (1) instruments measure the dose rates in air as roentgens; (2) a single dose in R from initial bomb gamma radiation is biologically different from the same total dose delivered over a longer time from a fallout field because of repair of radiation injury and a different depth-dose pattern in tissue. The fallout radiation produces a more uniform depth-dose curve than the unilateral bomb gamma, except at the skin surface where the fallout radiation produces a higher dose.

There are many problems yet to be analyzed further. I believe the Penalty Table may be improved upon by careful analysis of the effect of depth-dose patterns on killing of hematopoietic stem cells. However, significant improvement would require much more research and analysis on the significance of air dose rates from fallout fields. I believe it is particularly important to evaluate the dose rate meters to be used in respect to the energy cut off.

Is the energy cut off of the instruments used such that one can estimate the midline tissue dose realistically? If this has not been established, it needs to be established. In the absence of further research one cannot do much better than the Penalty Table in NCRP No. 42. It appears to be quite conservative and protective of human life after a nuclear disaster that would result in extensive fallout fields.

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SESSION A
Discussion

Victor P. Bond, Moderator

Dr. Bond: Rather than go strictly by speakers and the contents of their talk, we will orient this discussion period around general categories of subject matter. First we will discuss external radiation and its early effects, the LD_{50}, the Penalty Table, that sort of thing, then internal emitters, early effects, and then late effects, which means cancer and genetic effects, whether they be from internal or external exposures. We will proceed to the first subject area: External radiation early effects.

To introduce this, we're fortunate to have among us today individuals and groups from other countries. I'd like to start off by asking Dr. Spiers of the United Kingdom if he has any remarks on this overall area.

Dr. Spiers: I hope that what I have to say will not raise too much controversy. We have had in the UK some fairly recent discussions as to what the LD_{50} might be in terms of marrow dose. We have found, as Dr. Lushbaugh has so ably said, one or two anchor points at the bottom end of the scale that we have used. For dose effects in humans above these anchor points, his slides showed only too well how few these data are. He showed a series of accidents and exposures in which, as far as the accident cases go, you could pick out only one that was free either of trauma of some physical kind, apart from radiation, or of excessively non-uniform dose in which very serious burns had occurred to some parts of the body. It seems to me that in these circumstances it is not very wise to include these data.

The person who led all these discussions is someone you know well, Dr. Robin Mole. I'm sorry that he is not here. I'm quite certain that he could back up what I have to say. Nevertheless, the first bottom anchor point was the fact that in the last two or three years, considerable radiation doses have been given for the treatment of disseminated cancer, partly in Canada and now partly in our country—and I think in this country, too.

We have at least 20 cases of 300 rads of measured dose to bone marrow with no deaths recorded. If we include the cases where there is no physical injury, we have the Yugoslav accident with only one death and we have the Oak Ridge Y-12 accident with no deaths. One is hard put to scrape together more than one death from among the people who have been given between 300 and something more than 350 rads to bone marrow. A recalculation of the dose to bone marrow really anchors the bottom part of the curve at between 200 and 350. From there onwards we've had to rely on data from tests on large animals. I cannot defend this figure—I can only give it as the sort of guesstimate that we have made—that the LD_{50} lies somewhere between 400 and 500 rads to bone marrow. I agree that this figure is somewhat higher than the figures that have been given, but it probably is not too farfetched. However, I think one has to be prepared for considerable shifts either up or down because the human data are not there.

Let me put in an entirely non-scientific argument for choosing a value for the LD_{50} which is not too low: If you are going to calculate the consequences, then you must be conservative and adopt a low value—or as low a value as you think is reasonable. If, however, you are in an operational situation in which you are deciding whether a certain group of people has received so much dose that they cannot be rescued or that nothing can be done about them, then the lower you put the dose the more you are likely to discard people who might otherwise be saved. If nothing is done about them, they will certainly prove that they've had a lethal dose. I think there is reason for not putting the level, for operational purposes only, too low. I'm quite sure that scientifically we must try to find the best value, and, as all our distinguished predecessors have done, to give a pretty wide spectrum to that.

Dr. Lushbaugh: Could I say something here? I just wanted to make the point, which I did not make well in my paper, that all of us who believe in the 450 R or lower LD_{50} for man believe that this is a number for austere circumstances. We would agree on a higher LD_{50} for the Oak Ridge patients who were hospitalized for 6 weeks and were given very good care in a clean atmosphere, and for the Yugoslavians who were similarly housed in a beautiful hospital in Kiray Institute. We would expect these people to get well, but if you took a large number of these fellows and treated them as we do our mice and rats, put them in cages, throw food and water to them and then looked at them every 30 days, we would expect the LD_{50} to be lower than 450 R.

Dr. Spiers: The next point is one on which I have made some measurements myself: We used a nearly omni-directional incidence of radiation, more or less isotropic, running from quite low energies of about 50 keV up to sodium-24, by using multiple sources and therefore amply covering the spectrum that we're talking about; we used a more or less anthropomorphic phantom that is a real skeleton impregnated with soft-tissue-equivalent materials out into a rather ugly carcass made of PVC—polyvinylchloride—and filled with the tissue-equivalent materials. We made holes into the marrow site. With this arrangement, we measured the average marrow dose for an incident radiation for all directions. We came out with a figure which is very close to what you have in fact shown. We would say that in round terms, the conversion factor is that for the dose to the red bone marrow of the midparts of the trunk—not beyond the proximal ends of the limbs: It is 75% of what you would measure free in air with a Roentgen meter. Of course, you can convert to rads in air or to Grays or to anything else you wish, but at the moment I suspect that, like us, most of your meters are still air-filled Roentgen meters with Roentgen scales on them. So for the present, we have used the figure of 0.75. To quote one piece of Dr. Mole's work on the South American accident, that figure is based on the consideration that, following a dose of about 150 rads, there is an intracellular recovery. If you go on after that, there is a recovery in dose which is about 10 rads a day. These are two very rounded figures, based on the experiments with dogs and with sheep given an initial radiation, and with their LD_{50} followed up. This is topped up to a true LD_{50} dose.

Following Mole's work, we have adopted a very simple recovery program: We would say that a dose of 150 given within a day is recoverable and could be, in long term (60 days or more), neglected. Following that, you could take a recovery of 10 rads a day without expecting to worsen the radiation situation, again, purely in terms of recovery over a couple of months.

I think that is the burden of my talk. It can form the basis of good operational technique of a rather simple kind. For example, if you can say 10 rads a day can be sustained, then very quickly after an event like a large scale nuclear attack you could begin to let people out of shelter for very limited periods of time, say, 20 or 30 minutes a day. This would enable some things to be done which would break up this business of going to ground for 2 or 3 weeks. Shortly after that, you could say, "Well, three hours a day out of shelter", and perhaps later, "nine hours a day." This becomes almost total release, since very few of us spend all our time out of doors. I hope that adding this to your discussion will help.

Dr. Bond: Thank you, Dr. Spiers for those very thoughtful remarks. We're also fortunate in having with us Dr. Trott and some of his colleagues from West Germany. Dr. Trott was instrumental in putting together the German equivalent of the Rasmussen report, and has given a great deal of thought to these same questions. I would like to ask Dr. Trott now if he would care to make a few remarks.

Dr. Trott: Thank you, Dr. Bond. It's difficult after such a wonderful description to say something else. I only want to say that in Germany we are very much concerned about this very low value of LD_{50}. Most of the evidence we have, especially the recent evidence, is that many more people who got irradiation of more than the classic LD_{50} survived than died, so the value had to be bigger. I think an educated guess of around 500 rads isn't too far off the truth. But I want to address another problem which is very critical if you do something like a reactor safety study. Since the number of calculated fatalities depends much more on the slope you give to the LD_{50} value than on the LD_{50} value itself, then with decreasing dose, the number of affected people rises very sharply unless you give an LD_{50} of 500 rads and start the curves at an LD_{50} on the order of 350 rads. You won't see any people dying from a radiation dose of 345 rads.

If you look at how these slopes were arrived at, of course they couldn't come from human experience because this fortunately is very scarce. These slopes come from animal experiments in very good institutions where very much care is taken to have as homogenous a group of animals as possible. But the human population isn't like that. In the human population there are people who are ill, some very ill, and some have chronic infections. If you look at the type of damage these people get after total body irradiation, and if you combine this with the extensive experience of medical oncologists and hematologists on the treatment of bone marrow depletion syndrome and on the complicating factors, you immediately come to the conclusion that it must be a different situation if you have a very old man with chronic bronchitis with high temperatures. If you decrease the white blood count of such a person to less than a thousand, he will be in very much greater danger than a younger person who otherwise is completely healthy.

So, because of the inhomogeneity of the population and of the big progress that medical oncology and hematology has made in recent times, it's inevitable to adopt a much flatter dose response curve to any LD_{50} value you like than is printed in all the textbooks. We tried to account for this in the German reactor safety study and our slope—or standard deviation if you want to call it that—is about twice the number of the American one. And I think one should look more carefully at these problems. This again has many practical implications. Since the probability of survival depends so much on factors not related to radiation dose, you can influence the probability of survival by treating the complicating factors in time before the bone marrow depletion syndrome really sets in. I think on this line of thought one should give some more emphasis to this problem.

Dr. Bond: Are there any other individuals from another country perhaps or some organized group that has given a great deal of thought to this question who wishes to say anything at this point? Then we'll ask for individual questions and comments. Be sure to go to a microphone and to identify yourself.

Dr. Saenger (Cincinnati General Hospital): I don't want to say anything about slopes, I wouldn't understand anything like that, but back in the period from 1960 to 1970 we carried out a series of observations on patients given whole and partial body radiation at the University of Cincinnati. Our dose rate never exceeded something about 6 R per minute and our total doses got up to about 300 rads. The one thing that I think was quite impressive in the group of patients who had had chemotherapy and severe, rather extensive neoplasms, was that their hematological clinical responses were really not in proportion to their degree of illness. I am not happy with the concept that Dr. Trott gave that either the old people or the children are necessarily at greater risk because of their age or because of their infirmity. Further than that, if you look at the experience in pediatric chemotherapy of tumors, and see these children at very low blood counts existing in open wards with a lot of people with other diseases—this is going back over a period of over 20 years—I don't think the concept is entirely correct. I was amazed the other day, when we finally got around to doing our first case of bone marrow transplant in Cincinnati, to have one of my colleagues say that this is really a not very important method of therapy in the situation we're discussing today, because of the use of white cells and the fact that people are more resistant to depletion of bone marrow. Perhaps all these related debilitating illnesses are not really that important in the outcome of the individual given a particular dose of radiation.

Dr. Trott: I don't want this to be misunderstood. It is not the bone marrow sensitivity that is influenced by the underlying disease but the outcome of the disease. For example, whether a man dies from infection or not depends on whether he already has a drug resistant infection; if you add another complicating factor to that, then his fate is worse and I would not say that children are more sensitive—rather, I would say they are probably more resistant.

Dr. Weinberg (Oak Ridge Associated Universities): The issue that Dr. Trott and Dr. Saenger just raised has become peculiarly timely because of the big argument that is now going on with respect to the actual dose that one is likely to get from a reactor accident, especially a pressurized water or boiling water reactor. The fact that, at Three Mile Island, only 15 curies came out on the Island, when 60 million curies acutually got into the containment is now believed by many people not to be a fluke but to be characteristic of all water reactors. The very important implication of this finding, if it is indeed sustained, is that, as at least some people are arguing, the likelihood that there would be any immediate casualties from a reactor accident might be far lower than is computed either in the Rasmussen Report or in the Burkhoffer Report. I therefore would like to ask Dr. Trott if he would be willing to state, given his slope, whether there is, in fact, any threshold below which he would concede there is no immediate casualty.

Dr. Trott: Of course there is a threshold. It just depends on which one you take. If you go down to very low probabilities, you have to look at those figures on patients who were severely ill, got total body irradiation and died from it. Dr. Lushbaugh knows the data best, because his were the best data on this problem. It should be around 100 rads for very severely ill people. You just go down along with your curve, but again it's a matter of choice whether you go down to 150 or 100 rads.

Dr. Weinberg: I just want to ask Dr. Trott about the slope because, as I understand the problem of slope on a probability plot, as you decrease the slope so that it becomes flatter, you would put the LD_{50} pointer through the 50% point. Now you say you put the bottom of that line through the 100 rad. You now predict that there is somebody in our population who is going to be radiation resistant up at a level of about 3000 rads.

Dr. Trott: It depends on the way of plotting the data. We took the 500 rads point as in Wash-1400 and made the slope slightly flatter on the basis of normal distribution, as in Wash-1400. I gave Dr. Bond a reprint of a paper and the two curves are plotted one beside the other. It actually is not as bad as you think. The big problem is what happens to somebody if he gets 300 rads. In the American reactor safety study, everybody survives and we (the Germans) have about 10% fatality. That's the range of difference and I personally think that 10% is probably better than zero percent at 300 rads bone marrow dose.

Dr. Bond: Dr. Cronkite, do you wish to make any rebuttal remarks?

Dr. Cronkite: I don't think one can rebut when there are no data to rebut. Number one, I think that you can't really argue very much about Dr. Spiers' very well considered comments. There's repair in other animals and microorganisms, and I certainly accept that there's no reason why man should be different than other organisms; I just assume that there is some degree of repair and perhaps it is the order of 10 rad per day. I think that it's very difficult to say precisely where the LD_{50} for man is. One has to break it up by

TABLE A-3 Some Activities Induced in Nuclear Materials (5 MT, 50% Fission, Assumed Capture to Fission Ratio of 0.2)

	Curies			
Nuclide	1 Hour	5 Hours	40 Hours	10 Days
U^{239}	1.65×10^{11}	1.39×10^{8}	-	-
Np^{239}	5.50×10^{9}	6.35×10^{9}	4.13×10^{9}	3.53×10^{8}
Pu^{239}	21.5	1.06×10^{2}	6.85×10^{2}	1.68×10^{3}

	Curies			
	30 Days	90 Days	270 Days	1 Year
Np^{239}	9.60×10^{5}	-	-	-
Pu^{239}	1.77×10^{3}	1.77×10^{3}	1.77×10^{3}	1.77×10^{3}

TABLE A-4 Activities Induced in Soils (5 MT Surface Burst, Half of Escaped Neutrons Captured in Soil)

Nuclide	Curies at Zero Time				
	Igneous	Shale	Sandstone	Limestone	Sediment
Si^{31}	2.05 x 10^{7}	2.75 x 10^{7}	6.35 x 10^{7}	9.65 x 10^{5}	2.59 x 107
Ti^{50}	1.75 x 10^{7}	1.48 x 10^{7}	1.27 x 10^{7}	-	1.05 x 10^{7}
Al^{28}	3.19 x 10^{10}	4.36 x 10^{10}	2.31 x 10^{10}	8.65 x 10^{8}	3.56 x 10^{10}
Fe^{55}	1.29 x 10^{4}	1.45 x 10^{4}	4.72 x 10^{3}	4.83 x 10^{2}	1.17 x 10^{4}
Fe^{59}	6.85 x 10^{3}	7.65 x 10^{3}	2.34 x 10^{3}	2.17 x 10^{2}	6.20 x 10^{3}
Mg^{27}	3.23 x 10^{7}	3.17 x 10^{7}	2.56 x 10^{7}	4.07 x 10^{7}	3.18 x 10^{7}
Ca^{45}	9.10 x 10^{3}	7.55 x 10^{3}	2.28 x 10^{4}	4.18 x 10^{4}	1.43 x 10^{4}
Ca^{49}	2.11 x 10^{7}	1.98 x 10^{7}	4.94 x 10^{7}	9.75 x 10^{7}	3.76 x 10^{7}
Na^{24}	5.75 x 10^{7}	2.77 x 10^{7}	1.43 x 10^{7}	-	2.11 x 10^{7}
K^{42}	6.90 x 10^{6}	9.90 x 10^{6}	6.85 x 10^{6}	4.55 x 10^{5}	8.25 x 10^{6}
p^{32}	2.93 x 10^{4}	4.01 x 10^{4}	-	-	3.78 x 10^{4}
Ba^{131m}	2.08 x 10^{5}	2.08 x 10^{5}	4.16 x 10^{5}	-	-
Ba^{133m}	4.01 x 10^{3}	5.35 x 10^{3}	8.70 x 10^{3}	-	-
Ba^{136m}	8.50 x 10^{10}	1.04 x 10^{11}	1.78 x 10^{11}	-	-
Ba^{139}	4.99 x 10^{6}	6.85 x 10^{6}	1.17 x 10^{7}	-	-
o^{19}	3.23 x 10^{5}	3.23 x 10^{5}	6.45 x 10^{5}	-	3.23 x 10^{5}
Total Curies	1.17 x 10^{11}	1.48 x 10^{11}	2.01 x 10^{11}	1.00 x 10^{9}	3.57 x 10^{10}

TOPIC 4 SESSION B

Countermeasures for the Limitation of Radiation Exposure Following Wartime Nuclear Weapon Attack

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Introduction

Evaluating the consequences of a nuclear war requires consideration of post-attack conditions which have, over the past 25 years, caused strong polarization among the people of all nations, and indeed, the question of whether or not a nation can survive has been a subject of strong debate.

In order to discuss the work which has been done on post-attack recovery and especially countermeasures for the control of radiation in an extremely difficult environment, I must assume, as indeed I believe, that recovery from a large scale nuclear war is possible and worth considering.

In reviewing the literature, one finds that a substantial effort has been expended in studying the problem of exposure control after a nuclear attack. This effort goes back to Hiroshima and Nagasaki; it was in strong evidence during the period of atmospheric nuclear weapons testing in the fifties and early sixties and in the late sixties much of the work done was synthesized into planning documents.

During this period an understanding of nuclear explosion phenomenology and its interaction with the environment received a great deal of attention. Of great importance to the problem of exposure to radioactivity was the nature of fallout from an explosion detonated on the surface of the earth. Countermeasures to reduce exposure involved extensive work in theoretical analysis, in laboratory studies, in simulation experiments, and in field studies at nuclear weapons tests at the Pacific Proving Grounds and the Nevada Test Site.

Exposure control involved a number of basic concepts which were pursued at different levels of intensity as an understanding of the problem developed.

This afternoon I will discuss those concepts in some detail with emphasis on the problem of clean-up or decontamination of an area or facility.

Radiological Defense Countermeasures

A countermeasure system for nuclear war is defined as any combination of actions, preparations, or use of protective facilities and equipment that reduces or eliminates the hazards to human and physical resources following a wartime nuclear weapon attack. The major phenomena of nuclear explosions have been previously identified as (1) initial nuclear radiation, (2) thermal radiation, (3) blast and shock, and (4) fallout. The first three effects occur within a short time after the explosion and their impacts are symmetrical about the point of detonation. The impact from fallout occurs over a period of time after the explosion, and fallout radiation isointensity patterns extend a considerable distance downwind from the point of detonation.

The magnitude of the radiation intensity from fallout would be the largest when the explosion occurs near the surface of the earth.

The radiological hazard from fallout is characterized by the accumulation of exposure dosage over a period of time; therefore the specific objective of any radiological countermeasure is to reduce the exposure dose from radioactive sources in fallout. Since fallout dosage is delivered rapidly immediately following a nuclear weapon attack and because the doses delivered are in excess of lethal amounts in areas where heavy fallout occurs, radiological countermeasures must be concerned with survival. This early period of time is called the *Emergency Period.* During the emergency period the major type of radiological countermeasures would be shelter or shielding.

Radiological countermeasures during the recovery period following the emergency period are active countermeasures in the sense that they involve positive efforts to reduce the gamma radiation after the fallout has been deposited. These countermeasures include removing the fallout from surfaces (decontamination), burying the particles under the soil (land reclamation), and constructing temporary shielding with dense material.

Over some fallout contaminated areas, the radiation intensity would be sufficiently high that important facilities needed for post-attack survival could not be occupied and utilized within an acceptable period of time without decontamination. The purpose of decontamination is to permit reentry into fallout areas at earlier times than otherwise would be possible, and to reduce radiation dosages for target area reutilization.

The following discussion is limited to problems associated with the recovery of areas that are affected only by fallout or that experience very minor blast and thermal effects.

Fallout Characteristics as Related to Radiological Recovery Procedures

The essential characteristic of fallout from land surface nuclear explosions that are important considerations in radiological recovery operations are:

- The fallout consists of solid particles.
- The radioactive elements are fused into, or condensed on, the surfaces of the particles.
- Removal of the particles assures removal of the radioactive elements they carry.
- Under most conditions, fallout will be readily visible whenever a significant radiation hazard exists.

Except for soils with very high melting temperatures, a large fraction of the radioactive elements in the fallout will be fused into fairly large melted spheroidal soil particles where the radiation levels are high enough to require decontamination.

Although it is possible that decontamination methods using water as a flushing medium may leach out some of the radioelements condensed on the surfaces of the particles, this has not been observed to be a problem when the decontamination operation proceeds with movement of the mass of particles and water over the surface to a suitable drainage system.

Because the decontamination of fallout from land surface detonations can be described in terms of particle-removal and particle-transport mechanics, the requirements for data on the chemistry of both the interactions of the fallout with surfaces during deposition and the interactions during application of the cleaning procedures were recognized and studied in detail. Results of these studies shows these interactions to be insignificant.

Thus the choice and effectiveness of radiological recovery procedures is determined by the manner in which fallout is deposited and the makeup of the areas affected. Important surface factors in the choice of radiological recovery procedures include:

- *Surface type*—Paved areas, roofs, unpaved areas, agricultural lands, building complexes.
- *Surface Orientation*—Flat roofs, peaked roofs, gradient of paved areas, natural drainage patterns, vertical surfaces,

The effect of weathering on the distribution of fallout after its deposition must also be considered. The redistribution of fallout particles by wind and rain will affect the choice of decontamination procedures. The buildup of fallout particles will occur along curbs, around buildings in "dead air spots", planting beds and lawns, depressions in land areas, and open drainage features. Those types of areas will trap migrating fallout particles and consequently require manual decontamination procedures.

Performance of Radiological Recovery Methods

A great deal of research and effort has been conducted to develop decontamination procedures and to determine their effectiveness. These studies, conducted under controlled laboratory conditions, at weapon test programs involving land surface detonations, and at full-scale field operations utilizing simulated fallout, correlated the effectiveness of decontamination procedures with such parameters as fallout particle size and mass deposition levels, recovery effort, equipment capability, procedural applications and surface types. These studies have provided a basis for the development of Radiological Defense Planning Procedures.

The radiological recovery of essential facilities within a fallout contaminated area is a large and complicated process. Due to the wide variety of surface conditions that will be encountered, a wide assortment of equipment and manpower skills will be required. In areas of high fallout concentration, tons of accumulated fallout must be removed. This will require the utilization of a large work force and associated equipment supplies and material. The recovery of a given built-up target complex will require the coordinated application of several decontamination procedures such as sweeping, flushing, burial and soil-removal.

Obviously an operation of such magnitude must be preceded by an intensive planning stage. An unplanned radiological recovery program could achieve a reduction in the fallout radiation exposure, but the recovery effort might be greater than necessary, resulting in submitting recovery teams to larger than necessary exposure doses. Recovery planning techniques must include consideration of personnel exposure to obtain an acceptable balance between the reduction in fallout radiation and the cost in dose to recovery personnel. During decontamination operations, continual monitoring of exposure dose and effectiveness of the operation is necessary to insure reaching the required reduction in fallout radiation exposure.

Background and History

The first large-scale tests evaluating the performance of decontamination methods were carried out at Operation Jangle in 1951 at the Nevada Test Site. Paved areas and building surfaces were deliberately contaminated with fallout particles from a low yield underground explosion. Decontamination procedures studied included both wet and dry methods. Land reclamation experiments were also conducted.

The next set of large-scale experiments in fallout removal from paved and building surfaces were conducted at Camp Stoneman, CA, in 1956. In these experiments the wet methods of firehosing, motorized flushing, and the dry method of motorized sweeping were tested. Soil particles tagged with a radioactive tracer were used to simulate fallout particles. In 1958, a second series of Camp Stoneman tests were conducted with both wet and dry methods to determine their effectiveness at various levels of effort. Land reclamation procedures were also evaluated.

In 1957, at Operation Plumbbob at the Nevada Test Site, tests were conducted with motorized graders and scrapers to determine their effectiveness in the removal of fallout from land areas.

In 1961 and 1962, a test site at Camp Parks, CA, containing buildings, paved areas, streets, lawns, improved areas, was utilized to evaluate the radiological recovery of a target complex. The test site of approximately three acres was contaminated with a radioactively traceable fallout simulant. The entire site was then recovered using various decontamination methods.

The following discussion and results presented are based on the information obtained during these various large-scale field tests.

Decontamination Methods for Paved Areas and Building Surfaces

Decontamination methods for paved areas and building surfaces fall into two basic categories:

- *Wet methods*
  firehosing
  motorized flushing
- *Dry methods*
  motorized sweeping
  vacuum sweeping

The wet methods evaluated were all very effective in decontaminating land-type fallout from paved areas and building surfaces. Removal effectiveness levels of 98 percent could readily be achieved. These high removal effectiveness values, however, required large expenditures of effort and water.

Wet Methods. One of the first methods evaluated and utilized in large scale operations to remove radioactive fallout from paved areas and building surfaces was firehosing. Utilizing the extensive nationwide fire fighting capability, in terms of equipment and facilities, the method will generally be readily available in areas unaffected by blast and thermal damage. This method is easy to carry out and requires no special skills. Its success depends upon adequate water pressure, proper drainage and a certain amount of common sense in applying the procedure.

The usual procedure of decontaminating paved areas such as streets, sidewalks, and parking areas is to utilize a 1½ inch firehose operated by a two or three man crew. A nozzle discharge pressure of 75 to 80 lbs/in^2 is most effective.

In built-up areas, the water and fallout particles would be directed toward the nearest sewage drain or drainage ditch. A shallow pit dug by a bulldozer or by hand can also be utilized to collect the water and fallout particles.

Table 1 presents results of the decontamination of pavements by fire-hosing for various levels of effort. The results are shown for an initial fallout mass loading of 100 g/ft^2 which represents the mass level associated with a radiation intensity level of about 3000 R/hr at 1 hr after detonation. The effectiveness achieved is seen to be a function of the level of effort.

Large paved areas and streets can also be decontaminated utilizing motorized flushers. Motorized flushing can be done with either a conventional motor flusher or an improvised motor flusher. Unfortunately, street flushers are not nearly as plentiful as firehosing equipment. Street flushers can be improvised from tank trucks equipped with a pump and a single nozzle manifold.

Table 2 presents the fallout removal capability of street flushing, also for an initial mass loading of 100 g/ft^2. In comparing these results to firehosing, it is apparent that motorized flushing is much faster than firehosing and requires considerably less effort to achieve the same effectiveness levels.

Firehosing is the only method generally available for decontaminating roofs of buildings. Roof washdown systems, similar to those used by the Navy on ships, have been tested, but such systems would require installation in the pre-attack period and are very expensive and therefore are only suitable for special installations.

TABLE 1—*Firehosing pavements*

Mass Loading* (g/ft^2)	Effort $\left(\frac{\text{man-min}}{10^4\ \text{ft}^2}\right)$	Water Consumption (gal/ft^2)	Fraction Remaining (%)
100	15	.05	5.5
100	25	.08	3.5
100	50	.17	2.0
100	100	.33	1.0

* 100 g/ft^2 representative of a fallout radiation intensity of 3000 R/hr at 1 hr after detonation.

Source: USNRDL-467, Radiological Protective Construction, Jan. 1962.

The decontamination of roofs by firehosing can be conducted in two general ways. The firehose crews can operate from the roof itself or from ground level, lobbing the water stream onto the roof. The lobbing procedure is satisfactory only for roofs with sufficient slope for rapid runoff of water. On large, tall buildings, firehose crews would be required to operate from the roof itself.

Table 3 presents the results of firehosing tar and gravel roofs and composition shingles for various levels of effort and an initial mass loading of 100 g/ft^2.

Built-up roofing, such as tar and gravel roofs require more effort than the removal of fallout from composition shingles or other smoother roofing materials.

Most outdoor surfaces of structures are vertical. Vertical surfaces, however, do not retain a significant fraction of the deposited fallout particles from a nuclear explosion. The removal of fallout particles from vertical surfaces, from ledges, window frames or from other similar surfaces can be easily done by simple manual techniques such as garden hose flushing. However, since the contribution of the fallout on such surfaces to the gross radiation intensity would generally be small compared to the contribution from the fallout deposited on large horizontal collecting sufaces, the decontamination of vertical surfaces can be ignored in a large-scale decontamination operation until the major horizontal surfaces are decontaminated.

TABLE 2—*Motorized flushing of pavements*

Mass Loading* (g/ft^2)	Effort $\left(\frac{\text{man-min}}{10^4\ \text{ft}^2}\right)$	Water Consumption (gal/ft^2)	Fraction Remaining (%)
100	1	.045	5
	2	.09	3
	5	.22	1

* 100 g/ft^2 representative of a fallout reclamation intensity of 3000 R/hr at 1 hr after detonation.

Source: USNRDL-467, Radiological Protective Construction, Jan. 1962.

TABLE 3—*Firehosing roofs*

Mass Loading* (g/ft^2)	Effort $\left(\frac{\text{man-min}}{10^4\ \text{ft}^2}\right)$	Water Consumption (gal/ft^2)	Fraction Remaining (%)
	TAR AND GRAVEL ROOFS		
100	20	.30	6
	30	.45	3
	40	.60	2
	60	.90	1
	COMPOSITION SHINGLES		
100	5	.06	9
	10	.12	5
	20	.30	3

* 100 g/ft^2 representative of a fallout radiation intensity of 3000 R/hr at 1 hr after detonation.

Source: USNRDL-467, Radiological Protective Construction, Jan. 1962.

Dry Methods. As with firefighting equipment, most public works departments in cities, states, government facilities have available motorized sweepers and trained operators. Street sweepers were one of the first decontamination methods evaluated for the removal of fallout particles from paved areas. Table 4 presents the fallout removal capabilities of a conventional motorized sweeper and vacuumized sweeper. For both sweepers, the removal effectiveness is a function of the number of passes, or effort expended in the sweeping process.

Motorized sweepers are designed to pick up and contain the swept material in a hopper. Disposal in pre-selected disposal areas is quick and automatic. The buildup of contaminant in the hopper however, does represent a gradually increasing source of radiation to the driver. Therefore to keep the source of radiation from giving the operator too large an exposure dose, the hopper must be periodically emptied.

Decontamination Methods for Unpaved Areas

Large unpaved land areas may be decontaminated by removal of the contaminated layer of surface material and disposing of it by burial techniques using standard earth-moving equipment. Table 5 presents the effectiveness of various land reclamation methods for typical levels of effort. Fallout mass loadings have little effect on removal effectiveness. The total mass of earth handled is many times the quantity of fallout deposited.

TABLE 4—*Sweeping pavements*

Method	Mass Loading* (g/ft^2)	1st Pass		2nd Pass		3rd Pass	
		Effort $\left(\frac{\text{man-min}}{10^4\ \text{ft}^2}\right)$	Fraction Remaining (%)	Effort $\left(\frac{\text{man-min}}{10^4\ \text{ft}^2}\right)$	Fraction Remaining (%)	Effort $\left(\frac{\text{man-min}}{10^4\ \text{ft}^2}\right)$	Fraction Remaining (%)
Motorized	10	11	9	17	7	23	7
	30	9	7	16	5	20	3
	100	14	3	22	2		
Vacuum	10	20	7	30	2	40	1.5
	30	20	3	30	1.5	40	1.1
	100	20	2.5	30	1.2	40	1.0

* 10, 30, 100 g/ft^2 representative of fallout radiation intensities of 300, 1000, 3000 R/hr at 1 hr after detonation respectively.

Source: USNRDL-467. Radiological Protective Construction, Jan. 1962.

TABLE 5—*Reclamation of unpaved land areas*

Method	Effort $\left(\frac{\text{man-min}}{10^4\ \text{ft}^2}\right)$	Fraction Remaining (%)
Motorized Scraping		
1st Pass	5–8	<1
2nd Pass	4	<1/2
Motorized Grading and Motorized Scraping		
1st Pass	10–17	<1
2nd Pass	9–17	<1/2
Plowing	3–5	20
Earth Filling with Motorized Scraper		
6″ cover	10–20	15
12″ cover	20–40	2
16″ cover	40–80	<1/2

Decontamination of unpaved land areas can also be accomplished by covering the fallout with uncontaminated soil, or by turning the contaminated surface into the soil by plowing. The two latter methods employ soil as a shielding material.

The effectiveness of any of land decontamination methods is dependent on the thoroughness with which they are carried out. Spills or failure to overlap successive passes will reduce the overall effectiveness of the method.

Large-scale scraping operations require heavy earthmoving equipment to scrape off the top layer (several inches) of contaminated soil and remove it to suitable predesignated disposal areas. Motorized scraping is the most effective and efficient surface removal method. Motorized scrapers are designed to make shallow cuts into the soil surface, picking up the material into a hopper for disposal. The decontamination efficiency of motorized scrapers depend on the nature of the surface soil. They are extremely effective on large flat areas that have been sodded or tilled. Scraping operations can utilize motorized graders, motorized scrapers and bulldozers.

The motorized grader is designed for grading operations, such as for the spreading of soil or for light stripping. A motor grader can be used effectively on any long narrow area. The scraped up earth is placed in a windrow for removal or burial.

A motorized grader and motorized scraper can be utilized in combination to increase efficiency. In this combination method, the motor grader grades off the surface of the soil into windrows and the motorized scraper picks it up and carries it to a disposal area.

A bulldozer can be useful in scraping small contaminated areas, burying material, digging sumps and in back-filling disposal areas. It is also used as a prime mover to assist motorized scrapers in their scraping operations.

The principle need of placing an earth fill over a contaminated land area would be where scraping procedures could not be used because of rocky ground or permanent obstructions. The purpose of filling is to cover the contaminated area with uncontaminated soil to provide shielding. Motorized scrapers, bulldozers, graders and large dump trunks would be necessary for filling operations.

Plowing is a rapid means of decontamination by providing earth shielding as it turns the contaminated soil under and places a layer of uncontaminated soil on the surface. The depth of plowing should be at least 8 to 10 inches to achieve the effectiveness value indicated in Table 5.

Since it is not feasible to operate large earthmoving equipment in confined areas or around buildings, small garden tractors, or front end loaders equipped with a small scraper can be used for scraping or plowing. In some areas hand labor with shovels and wheelbarrows to remove fallout material would be necessary.

Cold Weather Decontamination Procedures

Cold weather decontamination methods will, in general, utilize the same procedures described previously. The presence of snow or ice could complicate the decontamination efforts due to a decrease in the mobility of equipment and personnel. Fallout particles may be clearly visible on or within a snowfall, or on ice. This may assist the decontamination process. The removal of a layer of snow or ice containing the fallout particles can be accomplished with readily available snow removal equipment. Motorized street sweepers can be used on dry pavements, traffic-packed snow or level frozen soil or ice covered areas.

Snow plowing can be utilized to windrow contaminated snow into piles for loading into dump trucks for removal to disposal areas.

Firehosing is possible and can be used on paved areas and exteriors of structures at below freezing temperatures. Firehosing under this condition should only be utilized when proper drainage is provided.

Disposal of Radioactive Fallout

One aspect of decontamination that has received very little attention is the ultimate disposal of radioactive fallout. The decontamination methods described in the previous section of this paper are designed to remove the source of radioactivity from areas requiring decontamination to areas of lesser importance.

In most instances, onsite burial of the fallout material is recommended. Sumps to contain runoff from wet decontamination methods can be backfilled after evaporation and/or seepage of the water into the subsoil.

Wet decontamination of paved areas in built-up areas will result in fallout particles washed into storm drains, which eventually lead to larger bodies of water such as a stream, river, lake or, in coastal areas, the ocean.

Fallout contaminated soil removed from land areas would be transported to areas for burial in excavated pits and then covered with uncontaminated soil, much the same way as sanitary land fills are operated.

Summary

In summary, one has to recognize that the post-nuclear war environment would present many orders of magnitude greater problems than would the most serious credible peacetime nuclear accident. The surviving population would have to live in a radiation environment that, by today's standards, would be totally unacceptable. Nevertheless there are a number of radiological countermeasures that can be taken to significantly reduce the radiation exposure in a post-attack environment. These include:

- Shelter—to take shelter upon warning (or before fallout arrives) and to remain in shelter until short-period operations outside the shelter are feasible.
- Decontamination—Conduct decontamination operations to reduce the dose rate in target-areas through removal of radiation sources.
- Evacuation—To evacuate personnel to areas that are outside of the path of fallout patterns after the dose rate in the shelter area has been reduced by decay and/or decontamination operations.

My discussion this afternoon was directed towards the usefulness of decontamination as one of the radiological measures to be utilized in controlling exposure dose following a large-scale nuclear weapons attack. The technology and equipment for implementing decontamination procedures are available. The major constraints in the determination of the usefulness of decontamination are: (1) the time required to accomplish the work and (2) the effectiveness of the selected decontamination procedures. The effectiveness depends only on the procedure itself and the surfaces worked on. The time required to accomplish the work has to consider dose constraints to decontamination crews, availability of manpower, equipment and supplies, size of area, type of surfaces and rate of application of the method.

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SESSION B
Discussion

Jack C. Greene, Moderator

Mr. Greene: Will the speakers please come forward and form a discussion panel. As all should know, much of the work that Jim Sartor described was done under the very able direction of Dr. Carl Miller who is with us today and will join the panel.*

Carl, I am very pleased to use this occasion to present to you a "certificate of appreciation" from the Planning Committee for this symposium, joined by members of the former NAS Advisory Committee on Civil Defense and others who have worked with you over the years. Here's what the certificate says:

> "We hereby present a Certificate of Appreciation to Carl F. Miller. Dr. Miller's many years of dedicated research have combined the best of theoretical and applied work and have resulted in an unparalleled contribution to our understanding of the physical and chemical characteristics of radioactive fallout, as well as the means for protecting against it. It is specially meaningful to those of us who have known and admired Carl over the years to have an opportunity to publicly acknowledge and honor the work of this extraordinary, versatile and innovative scientist".

We will start the discussion period by giving Carl five minutes to comment on anything he chooses.

Dr. Miller: Thank you very much. I appreciate this commendation and your comments. I might add here that thanks should also be given to my co-workers who helped me and did most of the hard work—this includes, of course, Pete and Jim who just completed their presentations. Sitting here and listening, I was impressed with many of the talks that were given. Starting with Lew Spencer's, I thought he did a very good job in giving the outline for the hazards to be discussed. One thing that occurred to me and probably occurs to a lot of you is that the real hazards in a nuclear attack are not from radiation—the real hazards are in the blast and other initial effects. Though his paper was clearly limited to the radiation effects, he knows, and you know, that the countermeasures against the other hazards would be more difficult to achieve.

Someone talked a little about risks. One thing that usually comes to my mind when risks are discussed goes back to World War II when I was in Burma working with the Chinese First Army as an artilleryman. We (and they) used to be supplied by airplanes that would fly over and parachute-drop food and ammunition and so forth. The thing about risk was that we used to watch the behavior of the Chinese soldiers—they would make bets on who could catch a sack of peanuts dropping down and they would truly try. I don't know what the LD_{50} for that "exposure" was or might be, but it was exceedingly high for a good catcher. It was a high risk game in a rather high risk environment. However, in the (now) old days, some of us at the then existing U.S. Naval Radiological Defense Laboratory did about the same thing with fallout at nuclear weapons tests.

In 1954, some civilians and Navy men were on a specially outfitted ship—a monstrosity bedecked with all kinds of sprinklers for testing the Navy washdown system. On one test, we were about 20 miles away when a 10-megaton shot was detonated. At the time, one piece of data we were interested in obtaining was the early time decay; also, additional data on the characteristics of the fallout were desired. My job was to put out a series of funnels, tubes and other things on this ship to collect some of the fallout. The ship was sailed on a pathway that led to an area directly underneath the expanding cloud so as to be exposed to a maximum amount of fallout. The ship, called the YAG-39, was highly instrumented with gamma detectors; it was accompanied by a sister ship, the YAG-40, which was operated by remote control but without the washdown system. Fallout arrived about 20 minutes after detonation, at which time I collected the first few drops of "hot" washdown water from tubing that extended from the deck to the bottom of the ship across from where the radioactive assay equipment was located.

In 1957, at the Nevada Test Site, personnel from NRDL and the AEC sat in an underground shelter a

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* We regret to inform the reader that Dr. Miller died in August, 1981.

mile away when Shot Diablo was detonated. Some of us collected fallout particles as they fell out of the sky from this event. We didn't chase after them on the outside of the shelter because we had little funnels and tubes running to the outside from inside. One could hear that stuff trickle down into containers in a deep cave from which we picked out single particles for assay. I was trying to do gamma spectometry on particles. I picked up one little particle, and the spectrometer just about blew up, so I quickly put it back in the cave and got a smaller one. That didn't work either: It was too hot. Finally, I got a little teeny one, but it was still too hot. So I took it back in and smashed it into smaller pieces, picked up a chip with tweezers and found out it didn't blank out the spectrometer. Of course, after about a half-hour or so, one could hardly get a reading on it anymore because of the rapid decay rate. Many people received some gamma exposure on ventures such as these. I did as well. That's probably one reason you see this dilapidated body in front of you with all the gamma rays that penetrated it over the years.

I like the way Jim Sartor brought out the character of the fallout, and Pete Strom, too. With most of the local fallout that we're talking about, a lot of the larger particles are fused or melted to form little glassy marbles. The tower shots had iron in them so they were magnetic and we could separate hot fallout particles from tower shots with magnetism. The radioactive atoms that could be absorbed into, or by, body organs were the few that are plated out on the surface of the fallout particles during the later stages of condensation in the fireball. That's why the elements iodine, strontium, ruthenium and a few other isotopes of that nature have been found in organs of animals and humans.

About a year ago, I worked on a project at the Center for Planning and Research that was sponsored by the State of California Disasters Office on reactor accidents. The part that I was interested in was the distribution model that was in the Rasmussen Report to show how the material from a reactor accident might be distributed around the countryside. Several things bothered me which I feel should be given further consideration and research—and especially, I would say, experimental research. I've never seen any kind of an observed particle deposition pattern that looks like that calculated from the models derived from the Rasmussen Report Systematics. Even the puffs that came (or leaked) out of underground detonations in Nevada don't look like the calculated patterns; to me, it appears that something is wrong or something is missing in the computer model distribution patterns. I just don't know what it is.

With regard to the previous presentations, one thing I would suggest is that Pete Strom might add to his paper a real tie-in between how the new, more advanced instrumentation would add to effecting controls on radiation doses in accidents of all kinds. I think with the accident problem one needs as much information as possible because of possible legal problems that could arise later. In all cases, with long range effects, one needs a lot more information than is currently available. For the early effects, a lot of fancy analyses are not possible because one doesn't have the time to do them before a decision or action of some sort is required.

Mr. Greene: We will move the microphone over to the panel's table. Suppose we address questions to the panel members starting at my far right and allow perhaps ten minutes for each question and answer. Are there questions for Dr. Gut?

Dr. Weinberg (Institute for Energy Analysis): I would like to ask Dr. Gut the following which bears a bit on remarks I am going to make this evening. I suppose Switzerland is now the country—aside from possibly the Soviet Union or China—where a larger fraction of the population has had some kind of direct contact with radiation and radiation meters than any other place in the whole world. Now do I misunderstand what's happening in Switzerland when I make that assertion? As I understand it, everyone has to be either in the Army or the Reserve in Switzerland, so I suppose everybody who gets in the Army has some contact with the radiation question—or is that not correct?

Dr. Gut: I think that is completely correct. We have in the Armed Forces the system for this. Information is distributed to very low levels, so that information about radiation and radiation effects goes to practically every soldier every year and, because the Swiss citizen has to do his two or three weeks of military service every year, he is normally updated in these respects every year. It's the same for the members of the Civil Defense organization. For the general population, there is also some awareness of radiation effects problems made available by Civil Defense organizations through the booklet that every Swiss citizen has at home. However, I think more could be done.

Dr. Weinberg: Have you seen any evidence at all that there is widespread understanding about radiation—that presumably most of the people in Switzerland (unlike the people in the United States) know the difference between a milliroentgen and a megaroentgen? Do you see any evidence that this increased sophistication has raised the level of understanding in the nuclear power debate in Switzerland?

Dr. Gut: That's a very difficult question to answer, but I'd like to try it. As you may know, we have had two votes with respect to nuclear power plants in Switzerland a year and a half ago. They were both in favor of the nuclear power plants, but only by a very slight margin. I think these votes showed that some information reached the people, because people are aware of radiation problems with nuclear power plants and with nuclear accidents. I think the process of getting adequate information to the people has just started.

Dr. Bryce (Armed Forces Radiological Research Institute): Dr. Gut, do the Swiss see a need for an integrating dosimeter or a neutron sensitive dosimeter?

Dr. Gut: Yes, like every other country that we have seen in the survey, we have radiation dosimeters—ionization dosimeters for zero to 50 roentgens—that's one kind. The other kind is for zero to 200 roentgens and it is distributed on the group level in the Swiss Armed Forces. That means that for every five to ten soldiers there might be such a radiation dosimeter. We also have for laboratories the dosimeters for zero to 200 milliroentgens. The same is true for the Civil Defense organization because we have the same equipment there, I think, as for the Armed Forces. We are now investigating the question of whether it will be necessary for us to have neutron dosimeters, too. We are studying that question now.

Mr. Du Temple (American Nuclear Society): Would you comment on the strategy that the Swiss military might be planning in the event you have a nuclear exchange between Europe and the Soviets, or in some other area? The reason I raise this question is that it seems to me that you're better prepared to take the fallout than most countries. In World War II, you held a unique position in that you had equal armament capability with surrounding neighbors and, of course, an excellent espionage system, so you knew what was going on. You had equal capability. You have very good knowledge of the terrain, and you threatened to inflict on the Wermacht some very severe losses. At the present time you don't have, as far as we know, equal weapons capability, but you have the ability to handle any particular fallout threat. Would this then lead you to mining your passes, etc. with nuclear explosives rather than conventional explosives in order to more or less neutralize the capability of your neighbors, if you had to?

Dr. Gut: I would like to answer partially. The strategy of our Swiss Armed Forces and the Civil Defense is a strategy of so-called total defense. We have all kinds of scenarios that we have included in this strategy. We have no nuclear weapons and there will not be such weapons in the future because it's not our strategy to have them. But we know that so many nuclear weapons are stored in Europe that it's completely clear that we have to be prepared for explosions of these weapons—maybe in neighbor countries or maybe in our country. So that's the reason why we adopted the strategy with the shelters because we had the impression that the shelter program can provide for sheltering against nuclear weapons fallout, against primary effects, and also against conventional warfare and chemical nuclear warfare, too. So the strategy is to have shelters strategically placed for everybody, which includes protection against all kinds of warfare that may be possible in the near future in Europe.

Mr. Greene: I think we'll hold other military strategy questions until the cocktail hour.

Dr. Storebo (Norwegian Defense Research Establishment): I have the feeling that my understanding of the word "control" is somewhat different from what I've heard here today. To me, it is not only a hardware word but also a software word. When it comes to fallout, I should guess that what we can do in software planning is to provide a much better fallout forecast. As it is now, I guess that the meteorological information which we really have is very much thrown away by the procedures we use. We normally use meteorological observations but smooth them out over large areas over long times. This certainly is not necessary today when we have computerized forecasts which include the wind, precipitation, and other dimensions of the weather. We are not, for the time being, utilizing all our capabilities for a fallout system. Concerning peacetime nuclear accidents, have you used operational analysis to study the best procedures for rescue? Also, I have not heard any meteorology considered here. If you are planning a delicate operation, the weather which is most probable should be taken into account, so the meteorologist should be asked very specific questions.

Dr. Strom: There is a nationwide emergency meterological system which is available and is operational.

Mr. Greene: Perhaps we should continue on this subject in a short rump session, and turn now to the other papers.

Mr. Haaland (Oak Ridge National Lab): I have a question and comments on the paper by Sartor. I was trying to visualize how one would apply the decontamination methods after an actual nuclear attack. Would you plan to set up hosing-down facilities around certain shelters, or would you plan to have them with some kind of rescue teams to wash away fallout from shelters that aren't capable of providing enough protection by themselves? Have you analyzed costs of this operation and how much dose does the individual get who's out there hosing down a paved area?

Mr. Sartor: There have been a number of planning studies conducted at Stanford Research Institute under Dr. Miller, and funded by DCPA or FEMA, where most of these questions you've brought up have been looked into in very much detail; the recovery after a fallout event, of course, requires a lot of consideration of all the things you mentioned: the cost, the timing, the training of the personnel. In the early periods after an attack in a heavy fallout area, people are going to have to remain in shelter. Recovery teams can come in from the outside to decontaminate large staging areas into which people can move from shelters in the heavy fallout areas. The costs associated with all of these operations have been calculated but, of course, in a post-attack environment I don't think anybody's going to worry about costs. I think they are going to worry about survival. The water is going to be available—we're talking now about the areas that have not been affected by blast and thermal damage. We're talking about the areas that are greater than 20/30 miles downwind and the water supplies in those areas should not be affected at all. So what I was discussing primarily is the survival of the people in the fallout area, not in the immediate blast and thermal area.

Dr. Weinberg: The very important point that you raised in connection with the nuclear accident and its aftermath goes as follows. If you examine the Rasmussen Report, and particularly the American Physical Society critique of the Rasmussen Report, it turned out that most of the casualties—better than half, that is—come from low level exposures to many, many people over a very long time because of the cesium-137 and similar isotopes. I must say, as I think about what is the rational reason why people are so afraid of nuclear energy, the only reason that I come to is this notion of interdiction of land. I want to put the question to you then: do you have some reliable number as to how much it costs to really recover the land and put it back essentially to where it was before the accident? That's a bit different from the response you gave in the case of a post-attack situation.

Mr. Sartor: I guess Dr. Cowper had some numbers for recovery from some incidents occurring in peace-time. George, do you want to answer that?

Dr. Cowper: There is the figure that has been quoted for Palomares, but I believe a large part of that was for the transmittal of the dirt to South Carolina and not directly connected with the removal work in Spain. Perhaps, there is someone in the audience who can make a better guess than I can how that sum of money may be apportioned.

Mr. Sartor: As for the recovery from the nuclear war fallout, we have all the data necessary to make that calculation. We know the manpower required, the effort, the fuel, the oil, the water. I don't think we ever attached dollars to those in our exercises. Following nuclear war, I think the demand for recovery is going to be such that the dollar is not going to be the problem.

Mr. Haaland: I want to address that. You might need to have on hand before a war more equipment than you might want. The question is: how many dollars must you spend before the war to prepare to decontaminate the way you would like to?

Mr. Sartor: I agree. That is a point that applies to all pre-attack planning.

Mr. Greene: Let me also make one point that I think is extremely important here. The amount of decontamination that one would do would depend on what levels one would be willing to put up with. And in terms of recovering large land areas, particularly agricultural areas, it would make a big difference what people like the NCRP advise on what could be tolerated in contaminated food or external exposures by the farmer who is plowing this land. So I don't think that one can arrive at a cost without specifying exactly what your end point is, and that has not been done.

Dr. Miller: I personally am against putting the land in quarantine, etc., based on cesium and other isotopes. I think that's ridiculous. If you go back in the literature, there has been a lot of work done at Davis, Oak Ridge, UCLA, Sweden, Norway and other places on the uptake of these isotopes by plants and how much gets in the wheat and the corn, etc. It's minimal. Everybody knows that cesium gets in the salt minerals and fits right into the shells in those crystals and they stay there. So for the uptake problem, forget it. We never did get evidence of the internal problem in any calculations for the early phases of any attacks that we studied at SRI. Putting in the worst assumptions we could about the solubilities and uptake and so forth, we could never make the internal hazard any problem whatsoever compared to the external gamma.

Dr. Taylor: I think a good deal of the answer to this kind of a question will arise through public relations. It's what the public thinks they want and what the public has been conditioned to think it wants. This is one of the things I'm going to speak a little bit about on Wednesday—namely, how the NCRP and others arrived at what we call our standards for protection. We arrived at those by a perfectly good process for normal peacetime applications. But if you try to apply those things to wartime or peacetime accidental situations, it's an entirely different question, and the public has to somehow or other be educated to this. The public relations people are not doing it for us.

Mr. Kaul (formerly from Defense Nuclear Agency and now with Science Applications, Inc. in Chicago): In the Rasmussen Study, I believe, the cost was estimated at about $1700 an acre to decontaminate up to a factor of 20 in the urban land and something around $1000 an acre for rural land. But the limit was the factor of 20 and the criteria had it that if, after ten years, a factor of 20 still wouldn't clean up the land, it was interdicted. That is interesting because the things that Mr. Sartor showed here on the screen indicated that 95–99% was a reasonable upper limit for decontamination; anything else that occurred subsequently with root uptake and what not is perhaps not so unreasonable. We have since done some calculations looking further at the problem of chronic uptake and its potential for denying land. It appears that based on the latest uptake coefficients, if you literally consumed 25% of everything that was deposited on the ground, approximately the same amount will be consumed from root uptake over a fifty-year period. Now this then gets us back to the discussions this morning.

What is the difference between consuming this stuff over a fifty-year period, consuming it in a one-year period, or being acutely exposed to it?

Mr. Kearney (formerly with Oak Ridge National Lab): I work with families and small groups trying to work out ways by which they can help themselves. In connection with decontamination, I'm working largely in Utah and Colorado and other places that are dry. The dust fallout or sand particles there can get all over you, and wading around in a fallout area seems highly undesirable. I wonder if you could give me an idea as to how long after the deposition of fallout do you consider it safe for people with poor protective clothing to get out and try to decontaminate? I'm not talking exposure to external gamma radiation.

Mr. Sartor: Two weeks is a normal period of shelter stay for most land surfaces. Fourteen days would allow you to come out into an environment where you could start decontamination.

Mr. Greene: There is one piece of work that I highly recommend. It was done by Dr. Mikhail at NRDL. He calculated the time after burst after which various amounts of radioactive fallout remaining for various periods of time on the skin would produce beta burns. If his calculations and assumptions are correct, and I've heard no one yet disprove them, after a period of two or three days you cannot get a beta burn from fallout. The specific activity is just not high enough. If that is correct, there is no need to worry about beta burns at the time you would be doing the decontamination, which would be at least a few days after the attack.

Dr. Storebo: It was refreshing to hear Dr. Strom's saying that we don't know what the particle size distribution of radioactivity is when you explode a bomb in a city. This is exactly the type of reasoning I tried to use in order to generate more interest in this. But I don't think that this is very important when it comes to cleaning up the radioactivity from a fallout area. I used this reasoning for changing the parameters in the predictions system, because there it certainly would have quite a lot of influence. But I couldn't go further on with this, because I simply don't know what particle distributions you will have from explosions in a city.

Mr. Greene: The time allotted to us has expired but if anyone is highly motivated and wants to stay on for further discussion, they are welcome to do so.

The results of the opinion poll have been tabulated for your reference:

OPINIONS ON PROBABILITY OF NUCLEAR WAR

Results of Poll Taken at NCRP Symposium
April 27, 1981

Probability of Nuclear War in Next Decade

Greater than 1 in 10	9	(8%)
About 1 in 10	17	(16%)
About 1 in 100	46	(43%)
About 1 in 1000	19	(18%)
About 1 in 10,000	16	(15%)
Total	107	

How Probability is Changing

Increasing	73	(62%)
Decreasing	12	(10%)
Not Changing	32	(27%)
Total	117	

Probability of Major Reactor Accident vs Probability of Nuclear War

Much greater for reactor accident	9	(8%)
Greater for reactor accident	27	(25%)
About the same	22	(20%)
Less for reactor accident	17	(15%)
Much less for reactor accident	35	(32%)
Total	110	

TOPIC 2 SESSION D

Preparations for Radiation Emergencies in the U.K. and Europe

John K. S. Clayton
Home Office, United Kingdom

Introduction

1. I am to talk about preparing people to face the prospects and actuality of a disaster that involves radiation hazards—all magnitude of disaster up to and including the ultimate catastrophe of nuclear war—and I shall do so from the point of view of a British Government scientist who happens to be most involved in planning and preparation for war emergencies. Although, for geographical reasons, we in UK are not much concerned with major natural disasters, we have to accept the possibility, however remote, of a major nuclear accident. I am not an authority on attitudes or plans in other European countries but I shall give you some information.

2. So I shall concentrate on measures for protection and survival in nuclear war in the United Kingdom, pointing out the most significant differences between preparations against those eventualities and peacetime disaster planning; and I restrict myself to the provision of information to and the training of four categories of people:

The general public—the broadest possible category;
The emergency service professionals;
The radiation protection authorities;
The decision makers.

3. I shall have to explain my definitions of those categories a little more fully but, before I do so, I would like to examine some principles that do, or should, influence our actions. I do so at some risk of trespassing on other speakers' preserves but I think it is relevant to my own subject to indicate how we think in UK. The principles I have in mind are:—

why we believe we should provide any information or training at all;
what measures are appropriate;
who is responsible;
when measures should be implemented.

When I use the word "we" here I include all of those in positions of responsibility for the planning or management of nuclear installations or operations, including military operations, or for the safety and well-being of the general public, whether we are Government servants or not.

General Considerations

4. The need for action arises because a threat is perceived to exist that can not be dismissed as negligible. Although the threat of an accident in peacetime may be judged small enough to be acceptable—and of course the threat of a disaster is less than the threat of an emergency as any motorist knows—nevertheless, some risk remains. A government can choose what level of risk of accident or disaster it will accept. On the other hand, it is not entirely free to choose whether or not to become involved in a war, and it has little control over the consequences of natural disasters.

5. The obligation for a government to take action is especially great if it has willed the risk into existence. Whether or not a democratic government will accept the obligation depends on both popular expectations and the extent of the people's influence. Public perception of risk may not coincide with that of the government, for the public is less well informed and may be misinformed. Even when there is agreement as to its nature, there may remain different degrees of willingness to accept the risk. Disagreements arise from deeply held moral or political convictions that are beyond the scope of this symposium: but we cannot afford to ignore altogether the fact that confusion and disagreement exist in sufficient strength to add significantly to the difficulties of presenting to the public what ought to be straightforward factual information.

6. How much authority should do is a matter for judgement relating to the likelihood of an incident, the severity of the consequences, the magnitude of any political repercussions (that applies to the peacetime threat) and, of course, the costs. It is not only a matter of deciding whether the costs are justified by the benefits, although that calculation is difficult and controversial enough. Any costs have to be met from

a finite budget at the expense of some other activity which may itself offer enhanced prospects in some other field for the preservation of life. Again public attitudes are important; and they are influenced by the extreme, and indeed alarmist, appraisals of risk propagated by some pressure groups to oppose vigorously projects designed to produce long term benefits, or to demand precautionary measures beyond all reasonable expectations.

7. Faced with this dilemma, governments tend to act instinctively rather than rationally, albeit with close regard to money supply and to what has been done previously and what is being done elsewhere. In particular, governments do, or should, consider carefully how any spending should be divided between measures to reduce the likelihood of disasters and measures to mitigate their effects, i.e., prevention (or deterrence) and protection.

8. That leads me to consider what measures are appropriate. We can say that they must be measures capable of implementation in the circumstances available at the time and likely to be effective. Thus, in the context of this talk, it would be confusing and therefore unhelpful to give people more information than they can comprehend, retain and apply; so training packages have to be well matched to the groups under training and those groups have to be selected to be reasonably homogeneous. Also it is important to distinguish between information that is essential, desirable or merely interesting. The desirable and interesting should be available: but publicity should be for specific purposes. The amount and type of information varies enormously with the composition and responsibilities of the group being informed, and here I shall attempt to particularize.

The General Public

9. I have suggested that the general public is a far from homogeneous body—it contains elements of varying size and importance, some incapable of facing facts or unwilling to accept them, or determined to reject them; some can understand what is, after all, a very complex problem, but many can't understand; some are apathetic or willing to cooperate or anxious to cooperate; others are unwilling to cooperate or are actively hostile; some are uninformed, some partly informed, some misinformed and some do not want to be informed; some of these trust authority to take any measures necessary or practicable, but some find the whole prospect unthinkable; there are those who are frightened or complacent; and those who are despairing or grimly determined; those who are morally shocked and resentful and others who are cynically accepting. Faced by this diversity of opinions and confusion of attitudes, officials planning to provide basic information must aim to keep the content of their packages both very simple and as uncontroversial as they can.

10. So a basic package might contain the facts that radiation is dangerous and to be avoided, without digressing into discussions about damage mechanisms or tolerable dose levels; that warning of danger will be given, with descriptions of the warning signals; that people will be advised or instructed how to act, perhaps with advance examples of the sorts of actions that might be recommended and advice as to what preparations might be made in advance, covering such aspects as protection within the home, food supplies and first aid; and finally that people will be told when the danger is passed, how they will be told and how they will be advised at that time.

11. That sort of information will not satisfy everyone. The more concerned and comprehending will want further information about the mechanisms of radiation damage; about the dose levels believed to cause injury or death to human beings, animals and plants; about the symptoms of radiation sickness; about the effects of radiation damage and of treatment; about the persistence of radioactive fallout and decontamination; about the organization of life, especially family life, under fallout; about shelter construction; and so on. In UK we think it is proper to make such information available to those who are concerned enough to ask for it, but unnecessary and perhaps unwise to inflict it upon the public at large. The principle source of information is the booklet "Nuclear Weapons" published by Her Majesty's Stationary Office, which covers much the same ground as your "Effects of Nuclear Weapons" but in less detail.

12. Within this more concerned section of the public are groups who need some detailed and specific instruction. They include the emergency services personnel and a range of other officials, and I shall come to them in a moment; and also groups of people with special responsibilities such as first aiders, farmers, factory managers or community leaders. I should explain that we hope in UK to be able to identify responsible people as leaders of small communities of a few hundreds of citizens, people who are sufficiently knowledgeable about the nature of the threat and the measures taken to provide an influence that is both soothing and constructive and who would cooperate with officials and government agencies. We aim to raise the level of understanding of such groups and individuals so they are presented with the information that is only on offer to the general public; and usually their training will include practising and exercising of acquired skills.

Emergency Services

13. In UK we have no national emergency service for peace or war. We disbanded our civil defence corps

in 1968. What we have are a number of organizations, some within central or local government structures and all depending heavily on voluntary effort. Their contributions are identified in and coordinated through emergency plans. However, both central and local government have very small full-time emergency planning staffs.

The emergency services in UK are:

Police
Fire Service
Ambulance Service
Health Service
United Kingdom Warning and Monitoring Organization (UKWMO)
Royal Observer Corps (ROC)

I should explain that the police function is mainly one of control; and the fire service mainly of fire fighting and rescue. The United Kingdom Warning and Monitoring Organization (UKWMO) and Royal Observer Corps (ROC) are mainly voluntary bodies responsible for issuing the national air attack warning, for monitoring levels of fallout and for giving public warnings of approaching fallout.

Emergency services provided by local authority departments are:

Food distribution
Housing
Public Health—sanitation, burial of dead
Demolition and clearance of debris—highways
Local radiac monitoring (wartime only)
Information to public (local)
Advice to public under fallout
Emergency planning

The local authorities are involved because they control extensive resources and their structures are readily adaptable to their extended or new tasks. We consider it undesirable—perhaps not even feasible—to set up new organizations to take over existing functions at a time of national crisis.

Emergency services provided by central (or regional) government or its agencies are:

Food supply
Water supply
Fuel and power
Air, rail or water transport
Military support to civil power

Equally the central government responsibilities remain as does the civil administration, although with some devolution. I should explain that arrangements exist for some reorganization of government and transfer of authority in any war crisis severe enough to make government from the centre impossible. Then elements of central government would disperse to the regions—there is no corresponding peacetime regional structure—while elected local authorities would lose their powers. However, local authority staffs would be absorbed into this wartime government structure performing more or less the same tasks but then as officers of a unified wartime government structure embracing all levels.

14. Personnel of all of these emergency services need and receive both general and specific information, with emphasis on the wartime role. They are taught the facts of nuclear war, which are new to most of them, and are led into structured discussions of their significance. They are told about planning arrangements, the organization of wartime government and their own responsibilities and, again, led into structured discussion usually by way of an exercise or "action game". They are told about the availability of specialist advice and, most important perhaps, about the role of the scientific adviser. Opportunities are taken within the discussions to consider lesser peacetime emergencies, noting especially the different powers and responsibilities for, in a peacetime emergency as in all but the most extreme war emergencies, central government and local authorities continue to function according to normal peacetime arrangements.

Radiation Protection Authorities

15. I mentioned the *scientific adviser* and I would like to emphasize his importance. Home Defence Scientific Advisers are volunteers (in peacetime) committed to serve at all levels of wartime government. They are recruited mainly from universities, technical colleges, and schools, but some come from industry and research establishments. They need to have a thorough knowledge of weapon effects so that they can analyse and interpret data, explain their significance, review the feasibility of operations proposed and advise on important matters such as the release of the public from fallout refuges. They have other duties as well which are important but less relevant to this talk. They have the most complete technical training of all volunteers, some ten days of basic instruction and perhaps another ten of advanced training, when they can specialize. All training is organized centrally and the training content is specified by my Branch. In addition regular continuation training or practising of skills is organized locally. Scientific Advisers participate in local or national exercises usually about once each year.

16. I restrict myself here to those people with specific responsibilities in peacetime who are, as you will remember, the staffs of the radiation protection authorities: and I make that restriction because the county emergency planning officers are, indeed, planners rather than operational officers. Now here I begin to move away from familiar territory so I shall be brief. Our National Radiological Protection Board has a prime responsibility for specifying safety standards in the light of international agreements; the Health and Safety Executive, through its Nuclear Installation Inspectorates is concerned with the enforcement of

standards at nuclear sites, and indeed for all sites where radioactive substances are used except only military sites and the laboratories of the Atomic Energy Authority. The Board, and all organizations in the nuclear industry, recruit professionally trained staff such as nuclear physicists and health physicists who, providing both expertise and a training capacity, perform the scientific advisory function full time and more professionally than is possible in the home defence field. The Board and the Authority both run training courses and some universities also run specialist radiation protection courses. The Board and the Executive both work closely with the Medical Research Council, which is a focus for academic knowledge, and with the Atomic Energy Authority.

17. The Health and Safety Executive is the licensing authority for commercial nuclear installations and is concerned with the safety of nuclear plants and their emergency plans. Safety is the responsibility of the managements concerned, for example the Central Electricity Generating Board; but the Executive's Inspectorate has to be satisfied that the plans meet safety requirements and that staff are familiar with them and are trained and exercised in risks and emergency procedures. Training is undertaken by the licensee's own staffs. A distinction is made between "on site" and "off site" emergencies; and plans for the latter have to be prepared with the cooperation of local authorities and national bodies such as, for example, the Health Authorities and the National Farmers' Union. Emergency plans are accessible to members of the public. The exercises are concerned mainly with control and deployment in an emergency, and some involve the local emergency services; but none involves the general public.

Decision Makers

18. My last category is the decision makers. Now decision makers exist at many levels: whatever the formal responsibilities, powers are delegated and, in the early stages of an emergency, decisions have to be taken by officials on the spot, before the more senior officials or ministers can be involved. Senior officers designated for regional and local levels in the wartime government structure are given the sort of indoctrination, adapted to the appropriate level, that I described when I spoke about the training of the emergency service personnel. Again, emphasis is placed on the importance of scientific advice; and officials are reminded of the importance of looking beyond the immediate crisis to social regeneration. It is difficult, of course, to persuade busy senior officers to give their time for this sort of training.

19. In addition, these same senior officers may be invited from time to time to cooperate in studies lasting two or three days, typically when government is considering changes in policy. The main object is to sound out opinions; but in order to participate in discussions they have to revise and apply their knowledge, so such studies provide a measure of continuation training.

20. Peacetime disasters are handled differently, necessarily by existing authorities. The principle is to act at as low a level as possible, at county police force and county fire brigade level unless there is a need to call on substantial resources from outside. Both police and fire services receive some training in dealing with incidents involving radioactive materials and are aware of the locations of such materials within their own areas. There is a machinery for involving central government, especially if the incident is severe enough to require coordination at that level, if central government or military expertise were required, or if the emergency were one of particular political sensitivity. Terrorist incidents would come within this category. Plans are made and the officials and security forces are exercised. Scientific advice would be important and would be provided normally by scientists from the Civil Service or the defence industries.

21. At the other end of the scale are minor incidents involving nuclear materials outside nuclear establishments, in transit for example. The major threats, nuclear weapons or materials being carried to or from nuclear power stations would be the responsibility of the authorities concerned, with the police involved in the control of the public at incidents. Minor threats at, say, the level of radioactive sources used for industrial or medical purposes, would be dealt with by the police who have scientific and medical expertise available to them through the NAIR scheme—National Arrangements for dealing with Incidents involving Radioactivity. The police can request a response from the nearest listed source of expertise, which may be one of the larger hospitals, or Atomic Energy Authority establishment or a defence establishment; and they are advised which hospitals are capable of dealing with radiation casualties.

Preparations in Sweden, Denmark, France

22. Now, I have been invited to say something about arrangements in other European countries. I am not well informed so I shall be wise to be brief. In particular, I have no details of information and training procedures; so I shall do no more than indicate the extent of civil defence and civil preparedness activities and we shall have to assume that the extent of the training programmes are appropriate.

23. There are as many solutions as there are nation states—perhaps more—and that is not surprising. But there are some good reasons for differences. Some European nations aim for neutrality, some perhaps

with some hope of maintaining it; while others include war in their contingency plans. To some in the latter group war could be expected to bring large scale land warfare on their home territories, with all that that may imply in terms of occupation and refugees; others in that group expect no major land warfare. All combatants must expect air attack, not necessarily with nuclear weapons (and assessments of that probability are tending to change), but with a risk of indirect effects of nuclear attacks elsewhere. In peacetime, a few European countries must expect to experience earthquakes; Italy, Yugoslavia, Albania and Greece come to mind: others are vulnerable to major sea flooding: but otherwise the likelihood of national disasters is small. A growing number have to plan for a peacetime nuclear disaster. I shall describe very briefly the arrangements in a sample of 3 countries.

24. The first is *Sweden*. The Swedes expect to have to face conventional attack in any war in Europe but they are less inclined to expect a direct nuclear attack than they were, say, 10 years ago. They have reviewed their policy recently. They have one civilian organisation to deal with the peace and wartime threats, which works in close association with the military; and their aim is to encourage people to fend for themselves. They have an evacuation (relocation) policy. Training is compulsory for civilians—until recently civilians were expected to train in their free time without compensation—and the duty is accepted. There is support from voluntary organisations. There is much publicity: a pamphlet has been issued describing protective measures in some detail; there is a civil defence magazine; use is made of the mass media; the voluntary organisations distribute their own information. There are 5 regional training centres with further training at county and unit level. Some 20,000 people receive formal training each year.

25. My second country is *Denmark*, which is closer to what is likely to be the main theatre of operations. The Danes expect both conventional and nuclear attack. They have again one organisation to deal with both peacetime and wartime threats, civilian but military in style. Thus it is manned by municipal employees, who may be directed into service, and by volunteers; but with the backing of conscripts and army reservists some of whom are formed into mobile columns. However, that organisation has only a coordinating function in a peacetime emergency. The Danes will encourage their people to "stay put" in war, because they believe their own homes will provide the best protection available and because they wish to keep the roads as free as possible. Publicity is through pamphlets, meetings, discussions, films and exhibitions. There are a National Staff College, a Civil Defence Technical School, mainly for training instructors, and facilities for training and exercising at unit level. The mobile columns are given more comprehensive training.

26. The last country is *France*. I shall not speculate about what sort of war she expects to fight but I can say that there is again one civilian organisation whose functions include research and practical studies as well as planning and training. The organisation is instructed specifically to look ahead to the recovery phase, which is unusual I think, and it is supported by voluntary organisations. A point of interest is the way the French organise to deal with peacetime disasters. They have ORSEC—their Organisation des Secours—which defines responsibilities, and includes an inventory of resources that are or can be made available, and the procedures to be followed as the local officials, who carry the first responsibility, need to call for national or military resources in aid. That scheme has worked well on a number of occasions. Information is provided through a booklet, information leaflets and brochures, the mass media, the cinema and through exhibitions at local functions. Specialist personnel are trained at state centres, the others locally.

27. A common factor I observe here is the extent to which the public are informed and expected to cooperate. In UK we have been very cautious indeed in releasing information and we have a public that is largely apathetic and to some extent hostile. It was the same in 1939 and 1940. Whether the apathy is due to the lack of a positive lead I would hesitate to say; but I think we must accept that in UK we have exploited the goodwill that we have a great deal less than we might have done.

28. The only European country that I know of which has separate organisations for Civil Defence and Civil Preparedness is Italy. There the Fire Brigades are expected to take the lead in peacetime emergencies and one may surmise that liability to earthquakes is a factor that contributes at least to the decision to organise that way.

29. That, then, concludes my survey. I shall not attempt to summarize: but, referring back to my rather lengthy introductory passage where I ranged over the subject of public attitudes and public needs, I am left wondering whether we pay quite enough attention to defining our objectives, in terms of who should know what, and to devising procedures that are really appropriate and effective.

APPENDIX A

Characteristics of the Nuclear Radiation Environment Produced by Several Types of Disasters, Summary Volume

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I Introduction

A. *Background* (updated by editor of Proceedings)

The National Council on Radiation Protection and Measurements (NCRP) is holding a symposium on radiation protection in the aftermath of a variety of nuclear disasters that might occur in either peacetime or wartime. The symposium is a preliminary step in the work of a new NCRP scientific committee established to examine and advise on controlling the exposure of the population from such radiation hazards.

In support of the symposium, SRI International undertook an investigation to summarize the current state of knowledge concerning the radiation environments to be expected as a result of several types of disasters. The results of that investigation will provide a reasonably comprehensive description of the environment to be expected from each of seven incidents that would result in radioactive contamination of sizeable areas [1]*.

This report summarizes the results of those investigations; it is intended to provide speakers and other participants at the symposium with a common set of assumptions concerning post disaster environmental characteristics.

B. *Content*

Table 1 summarizes the content of this entire report. The incidents are identified along the top, and the environmental factors are listed down the left column. The results of the investigation occupy the central part of the matrix. The remainder of this report provides some clarifying discussions and amplifications of the material contained in Table 1. The incidents are discussed in the order shown across the top of the table, and, for each incident, the discussion follows the order of the environmental factors in the left column of the table.

II Multiweapon Attack

A. *Introduction*

A hypothetical strategic attack on the U.S. that has been used in several recent studies was chosen for this investigation. The attack is described in more detail in later portions of this section.

All weapons employed in the hypothetical attack have yields ≥ 1 megaton. With such weapons, the initial nuclear radiation emitted within the first minute after the explosion is a minor threat when compared to the effects of blast and thermal radiation. The radiation environment of concern is limited to the residual radiation contained in the fallout (surface and near-surface bursts) or the induced activity in the ground (air bursts).

B. *Properties of the Radionuclides*

1. *Sources of Residual Radiation*

The residual radiation arises mainly from three types of weapon debris: fission products created when uranium or plutonium atoms are split; unfissioned uranium and/ plutonium atoms; and radioactive iso-

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* References are listed at the end of this report.

Table 1

RADIATION INCIDENT/ENVIRONMENT MATRIX

Incident / Environment	Weapon Attack		Power Reactor Accident		Transportation Accident		Transoceanic Fallout
	Multiweapon	Single Weapon	Core Melt	No Melt	Surface Transport-Spent Fuel Rods	Air Transport-Weapons	
1. PROPERTIES OF RADIONUCLIDES							
a. Sources of Radiation	Radioactive nuclides in particles of soil and/or weapon debris. (Fallout)	(1) Initial Radiation from nuclear explosion plus interactions with surroundings. (2) Fallout particles.	Aerosol (solid, liquid, vapor, gas)	Aerosol (liquid vapor, gas, solid (dust))	Gases, vapors, aerosols (dust), depending on release mode.	Extremely fine particles to very large pieces of weapon debris.	Fine particles of soil and/or weapon debris
b. Radioisotopic Composition†	(1) Fission Products (>300 isotopes (2) Activation Products (Weapon and surroundings) (3) Unfissioned Debris	(1) Initial Radiation: Neutrons and gamma rays from fission and fusion reactions; gamma rays from de-excitation of fission products, and from neutron interactions. (2) Residual: same as for multiweapon.	Fission products, activation products (see Table 2)	Fission products, activation products (see Table 2)	Isotopes of: Volatile: Kr, Te, I, Cs. Non-Volatile: Sr, Y, Zr, Nb, Ru, Ce. Actinides: Pu, Am, Cm.	Pu-239, Pu-240, Pu-241, Am-241.	Sr-89, Sr-90, Ru-106, I-131, Cs-137, and Ba-140.
c. Chemical Properties	Inert gases (Kr, Xe) in elemental form; other isotopes primarily in various compounds-some soluble, some insoluble. Most (including some Kr & Xe) trapped in relatively large, insoluble particles.	Same as multiweapon	Various chemical compounds and elemental forms (see discussion)	Same as for core melt - larger fraction present as gases and vapors	Similar to reactor accidents	PuO_2	Various compounds in small particles of inert weapon residues or soil

Notes:
- Much of this information must, of course, be based on estimates.
- In multiweapon attacks, assumptions are limited to residual radiation from high-yield weapons.
- In single weapon attacks, assumptions are limited to initial and residual radiation from low-yield weapons.
- The specific isotopes listed are the most important for that incident.
- Only the most important radiation types are shown; the types of incidents considered include α, β, and γ radiation.

Table 1 (continued)

RADIATION INCIDENT/ENVIRONMENT MATRIX

Incident / Environment	Weapon Attack		Power Reactor Accident		Transportation Accident		Transoceanic Fallout
	Multiweapon *	Single Weapon **	Core Melt	No Melt	Surface Transport-Spent Fuel Rods	Air Transport-Weapons	
d. Particle Properties	Fused soil and/or construction materials or weapon components. Diameter $\geq 50\ \mu m$[1]	Similar to multi-weapon. Diameter $\geq 20\ \mu m$[1]	Aerosol particles $\sim 3\mu m \leq \text{Diam} \leq \sim 50\mu m$	Same as core melt, but particles make up smaller fraction of the total	Dust aerosols generally <200 µm; small percentage (<10%) are <10 µm; very speculative.	Most are small particles (<20 µm) of PuO_2. Mean (particle quantity) diameter ~2 µm. Can have a few large chunks.	Similar to multi- or single-weapon attack. Diameter generally ≤ 25 µm. Few between ~ 20 and 50 µm for megaton yields.
e. Biological Availability	Most radioactivity in or on large insoluble particles-external hazard overwhelms the internal for early times-some problems from ingestion at late times (see discussion)	Similar to multi-weapon. For isolated explosion in peacetime, there will be a long term concern about ingestion of food-stuffs grown in contaminated areas, and, to a lesser extent, from inhalation. Inhalation of particles < 10 µm during initial cloud passage could result in retention of quantities of radioisotopes that would be significant during peacetime.	Smaller particle sizes result in greater biological availability than is true for weapon products. Most radioisotopes are contained in compounds, many of which are insoluble.	Generally smaller particle sizes in the distribution than for core melt, resulting in greater hazard from inhalation for equal concentrations in air.	Inhalation is prime concern; very dependent on assumptions concerning particle size distribution, which is very poorly known.	Prime concern is inhalation of Pu. Requires exposure to the cloud, which is small, or resuspension of small (<10µm) particles.	Small particle size allows long term suspension in liquids almost like being soluble. Availability depends on amount of filtration by pathways, i.e., animals and plants.
f. Radiation Types	Gamma (external)	Initial: Gamma, Neutron Residual: Close in: Gamma (external) At a distance from explosion: Beta, gamma (internal)	Gamma (external) Beta, gamma (internal)	Beta, Gamma	Beta, Gamma	Alpha	Beta, gamma (internal)

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[1] For high-yield weapons in multiweapon attacks—for low-yield weapons in single weapon attacks.

Table 1 (Continued)

RADIATION INCIDENT/ENVIRONMENT MATRIX

Incident / Environment	Weapon Attack		Power Reactor Accident		Transportation Accident		Transoceanic Fallout
	Multiweapon *	Single Weapon **	Core Melt	No Melt	Surface Transport-Spent Fuel Rods	Air Transport-Weapons	
g. Energy of the Radiation	Primarily Fission Product Spectrum extending from 0 to >3 MeV at early times; softer at later times; Effective energy of 1.0 MeV sometimes used.	<u>Initial</u>: <u>Gamma</u>: Spectrum up to ~10 MeV. Effective energy of 1 MeV sometimes used. <u>Neutron</u>: Spectrum from thermal to 14 MeV. <u>Residual</u>: As for Multiweapon.	<u>Gamma</u>: Similar to multiweapon fission product spectrum. Induced activities, e.g., Co^{60}, may be important. <u>No Neutrons</u>.	Similar to core melt except that individual isotopes (Xe^{133}, Kr^{85}, Kr^{88}, I^{131}) become more important.	Similar to core melt.	Alpha: 4 to 5+ MeV. (Mostly 5.15 MeV). Early times: 364 keV (I^{131})	Beta: ~0.5 to ~1.5MeV Gamma: Various low energy, low intensity plus: Early times: 364 keV (I^{131}) Late times: 662 keV Cs^{137}
h. Decay Characteristics	$\dot{D} = \dot{D}_1 t^{-1.2}$ $\dot{D}$ = Dose rate at time t (R/hr). $\dot{D}_1$ = Dose rate at 1 hour after explosion (R/hr) t = time of interest (hours) Approximate; adequate for planning.	Same as multiweapon.	Limited number of isotopes important at various times, and more limited number important for external or internal dose. Decay individually with appropriate half-lives.	Same as core melt.	Same as core melt, plus point source of essentially constant intensity over periods of days in the case of fuel assembly ejected from shipping cask.	Pu^{239}: $t_{1/2}$=24,400y	Sr^{89} : $t_{1/2}$= 52d Sr^{90} : $t_{1/2}$=28.1y Ru^{106}: $t_{1/2}$=367d I^{131}: $t_{1/2}$=8.07d Cs^{137}: $t_{1/2}$=30.2y Ba^{140}: $t_{1/2}$= 12.8d
2. AREAS AFFECTED a. Incident Description	Strategic attack on the US. 1,440 weapons 6,559 megatons total 5,051 megatons surface burst All weapons ≥ 1 megaton yield	(1) Single 1 kt surface burst or (2) Single 40 kt low air burst.	Failure of core-cooling system results in core melting concurrent with failure of containment spray and heat-removal systems. Substantial puff released for about 1/2 hour; followed by continuous release at a low rate.	Large pipe break; containment fails to isolate properly on demand. Other safety features function properly. Release occurs over about 0.5 hour time, during which the containment pressure would be above ambient.	Major accident involving truck carrying spent fuel.	Peacetime crash of bomber loaded with 1 or more nuclear weapons. Detonation of high explosives in a weapon occurs. No nuclear yield.	Sino-Soviet nuclear war employing both strategic and tactical nuclear weapons.

Table 1 (continued)

RADIATION INCIDENT/ENVIRONMENT MATRIX

Incident / Environment	Weapon Attack		Power Reactor Accident		Transportation Accident		Transoceanic Fallout
	Multiweapon *	Single Weapon ** 1-40 kt	Core Melt	No Melt	Surface Transport-Spent Fuel Rods	Air Transport-Weapons	
b. Extent of contamination (see Discussion for Explanation and More Quantitative Results)	Millions of square miles. Major segments heavily contaminated. Most of the rest are lightly affected.	Few square miles heavily contaminated. Larger areas lightly affected.	Uncontained core melt: up to a few square miles of heavy contamination. Up to a few 100's of square miles lightly affected. Contained core melt: very light contamination for up to a few 100's of square miles.	Same as core melt with lower consequences.	1 to few hundred square miles.	~1 square mile	Rainy areas during fallout cloud passage.
c. Population Exposure	Up to 100 million fatalities. Essentially entire population exposed to some radiation.	<u>Prompt Casualties</u> 2,000 to 110,000 depending on yield (1 to 40 kt[2] ~10^6 persons exposed to radiation from fallout (1 kt)	Up to 2 million persons. Very few to LD/50 or greater dose.	Same as core melt with lower consequences.	0 to few thousand persons exposed.[3] Few, if any, to LD/50 or greater dose.	0 to ~1000 persons exposed[4]. Few, if any, to LD/50 or greater dose.	Potential exposure of a hundreds of thousand persons to low-level doses.
3. DOSIMETRY a. Requirements (see discussion for quantities)	β-γ survey meters dosimeters chargers	Same as multiweapon plus low intensity gamma survey meters (and/or Alpha survey meters), air samplers, airborne gamma Spectrometer with low intensity sensors and computing capability.	Same as single weapon.	Same as single weapon.	Same as single weapon.	Low intensity gamma survey meters and/or alpha survey meters.	Airborne gross-beta activity measurement, capability. Beta-gamma survey meters.
b. Available Instruments	Requirements exceed available supply by factor of 5 to 10.	Probably adequate, but rapid relocation probably would be required.	Adequate	Adequate	Adequate quantities, but rapid movement would be required for most locations.	Adequate.	Adequate.

[2] Optimum ground zero for 40 kt over Detroit.
[3] Assuming population density from 0 to 1 per km^2.
[4] Assuming population density from 0 to 1000 mi^2.

Table 1 (concluded)

RADIATION INCIDENT/ENVIRONMENT MATRIX

Incident / Environment	Weapon Attack		Power Reactor Accident		Transportation Accident		Transoceanic Fallout
	Multiweapon *	Single Weapon **	Core Melt	No Melt	Surface Transport-Spent Fuel Rods	Air Transport-Weapons	
4. COUNTERMEASURES (see discussion)	Shelter Relocation Decontamination	Shelter Relocation Decontamination	Shelter Relocation Decontamination	Shelter Relocation Decontamination	Relocation Decontamination	Relocation Decontamination	Control of food and drink.
5. LIKELIHOOD AND CONSEQUENCES a. Probability.	Probability impossible to determine; one analysis put the probability at 0.03 per decade.	Perhaps greater than multiweapon attack.	~0.06 per decade based on 111 reactors and 5×10^{-5} per reactor year.[5]	~0.1 per decade based on 1×10^{-4} per reactor year.	Severe accident ~0.01 per decade based on assumed 90,000 vehicle miles per year.	~4×10^{-7} per flight.[6]	<0.1 per decade.[7]
b. Consequences	20-160 million immediate deaths; possibility of many subsequent fatalities; large scale economic destruction and disruption.	Hundreds to tens of thousands immediate deaths depending on location and yield; possibility of subsequent fatalities and other long-term effects; destruction and economic upset that would be considered large scale in peacetime environment.	~3×10^{-5} early fatalities per-reactor year.	Possibly some late fatalities and genetic effects.	No early fatalities; possibly early sickness for few persons; possibly some late fatalities and genetic effects.	No early fatalities or casualties; possibly some late deaths and genetic effects; isolation and/or decontamination of area required.	No early fatalities or casualties; high infant thyroid exposures likely without control of milk.

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[5] Value given in Reactor Safety Study (Rasmussen Report) as probability of a core melt resulting from any set of circumstances. Later investigations taking updated look at the same baseline reactor arrive at a core melt probability of 1×10^{-4} per reactor per year.

[6] Assumed about equal to probability of fatal crash on U.S. commercial airline on domestic flight (see discussion).

[7] Assumed somewhat less than multiweapon attack on the U.S. for 10-year period commencing 1980.

topes formed by interactions of neutrons with weapon materials. Another source is radioactivity induced by neutrons interacting with elements present in the media surrounding the explosion.

The primary hazard results from the creation of fallout particles following a land surface or subsurface burst. Radioisotopes from the 3 sources mentioned above condense on soil and other particles that are sucked up into the fireball. These particles may be dispersed over large areas by the wind in patterns that can be predicted only approximately when details of the weapon design and the weather are well known.

2. *Isotopic Composition*

Fission products are the predominant source of radiation in fallout. These include more than 300 radioactive isotopes of about 38 elements of medium atomic mass (~72 through ~162 atomic mass units).

Activity induced in weapon materials is highly variable. U-237 and -239 and Np-239 and -240 can be significant contributors, particularly during the period from 20 hours to 2 weeks after burst.

Neutron interactions with 0-16 and N-14 in the air produce N-16 and C-14, respectively. These have half-lives that are so short (7 seconds for N-16) or so long (5,730 years for C-14) that they are hazards either immediately or only in the long term but not during times of most concern from fallout. Of the elements in the earth and sea water, Na-24, formed by neutron capture by Na-23, deserves most attention. It has a 15 hour half-life and emits relatively high-energy gamma rays as well as beta particles. At early times, Mn-56 (half-life = 2.6 hours) can be a serious hazard. Tritium is formed in fusion reactions, to a lesser extent in fission, and by interaction of neutrons with nitrogen. It is rapidly converted to tritiated water and becomes associated with natural water where it is available for consumption.

3. *Chemical Properties*

In general, the radioisotopes in fallout will behave chemically the same as the non-radioactive isotopes of the same element. The excitations involved in decay processes will affect chemical reaction rates, and the element changes associated with β decay will cause a continuing assortment of reactions. The following discussions suggest chemical forms that may be found, but, due to the large uncertainties concerning reaction rates at the temperatures involved in an explosion and with the highly excited states of many fission products, any chemical form should not be viewed as completely unexpected.

- *Noble Gases (Kr and Xe):* Being chemically inert, these elements will be gaseous and in the elemental form if free in the atmosphere. They may, however, be trapped or absorbed in a solid particle.
- *Halogens (I and Br):* Iodine is the most important. These may be in the elemental form, in which case iodine is likely to be a gas. They may also be found as iodides, bromides, iodates, or bromates.
- *Alkali Metals (Cs, Rb):* These will probably be found as oxides or hydroxides. Iodides are also possible.
- *Noble Metals (Ru, Rh, Pd, Mo, Tc):* These may be found as oxides, hydroxides, or in the elemental form. Molybdates and pertechnetates are also likely.
- *Alkaline Earths (Sr, Ba):* These will probably be found as oxides.
- *Rare Earths (including Y, Np, Pu, Zr, Nb):* These probably will be sequioxides or dioxides (Np and Pu). All have extremely low volatility.
- *Tellurium and Antimony* likely will be present as extremely volatile oxides.

4. *Particle Properties*

The physical nature of the particles that reach the earth as fallout depend on factors such as height of burst, atmospheric conditions and the nature of the earth's surface at the burst point.

No surface material is taken into the fireball by an air burst. The particles consist of condensed radioactive residues of the weapon materials with diameters ranging from 0.01 to 20 μm. These particles remain airborne for long periods of time, and in the absence of rainfall, early fallout is insignificant.

As burst height decreases, earth, dust, and other debris from the earth's surface are taken into the fireball. Fission (and other radioactive) products condense onto particles of appreciable size (1 μm to several mm). The larger ones begin to fall back to earth while the cloud is still rising, while the smallest ones remain suspended in the atmosphere for long periods. The early (24 hour) fallout generally includes particles with diameters of a few tens of micrometers and larger, with the lower limit being dependent on yield.

5. *Biological Availability*

The amount of radioactive material absorbed from early fallout by inhalation appears to be small. The nose filters particles larger than about 10 μm and 95 percent of those exceeding 5 μm. Most particles in the early fallout exceed 10 μm.

Absorption through the intestine is largely dependent on the solubility of the particles. A majority of the fission products as well as the uranium and plutonium are chiefly present as oxides, many of which do not dissolve to any great extent in body fluids. Many of the radioisotopes that are soluble are trapped in large insoluble particles, so absorption into the blood stream is inefficient.

6. *Radiation Types*

The fission products form a mixed beta-gamma radiation source with a few neutrons during the first few minutes. The unfissioned uranium or plutonium, some of the transuranic elements, and many of the daughter products of these isotopes decay by alpha emission. The fallout field, therefore, is made of up alpha, beta, and gamma emitters. The external hazards to humans is almost entirely due to gamma rays, although prolonged contact with the skin cause beta burns. All three radiations can be hazardous to humans if the emitters enter the body. External beta and gamma radiation both can be important to plants, particularly during their growth period.

7. *Energy of the Radiation*

The gamma radiation from fallout is relatively low energy radiation in contrast with gamma rays emitted at the time of a nuclear explosion. At early times, there are a few gamma rays with energies greater than 3 MeV, but most of the radiation consists of gamma rays with energies less than 1 MeV. An effective energy of 0 MeV is suitable for many purposes. The beta radiation displays continuous energies up to about 5 MeV, while most of the alpha particles are in the energy range between 4 and 6 MeV.

8. *Decay Characteristics*

Each of the more than 300 isotopes in the fallout field decays with its own characteristic half life. When the contributions of all isotopes are summed, it is found that for times between 30 minutes and about 5,000 hours (200 days), the theoretical decrease in dose rate with time can be approximated to within 25 percent by the simple expression.

$$R_t \simeq R_1 t^{-1.2},$$

where R_t is the gamma radiation dose rate at time t after explosion and R_1 is the dose rate at unit time.*

The expression is only applicable if there is no change in the quantity of fallout during the time interval under consideration. It cannot be used for periods while fallout is descending or if the fallout is moved, e.g. by weathering, washing, etc.

Measurements indicate that the $t^{-1.2}$ decay is a reasonable average, but exponents have been observed in the range between −0.9 and −2.0. Furthermore, overlapping fallout from two or more explosions occurring at different times will have completely different decay characteristics. The decay rule is useful for making estimates, but the estimates should be verified by measurements as frequently as possible.

C. *Areas Affected*

1. *Attack Description*

The hypothetical attack selected for use is a strategic attack on U.S. military installations, military-supporting industrial and logistics facilities, other basic industries, and major population centers.

The attack consists of 1444 weapons with a total of 6,559 megatons, of which 5,051 megatons are surface bursts [2].

3. *Population Exposure*

More than 67 million persons are located in areas receiving unit-time reference dose rates in excess of 3,000 R/hr, more than 159 million in areas receiving in excess of 300 R/hr, and more than 188 million in areas in excess of 30 R/hr.

The dose rates mentioned above would not necesarily exist since the deposition would take place over an extended time period and the fallout is decaying while deposition takes place. The four-day doses, which consider arrival time and which represent most of the lifetime accumulations, corresponding to the above-mentioned unit-time dose rates are 5,400, 360, and 24 roentgens, respectively. Shielding or relocation could reduce these accumulated doses.

D. *Dosimetry*

1. *General*

It is certain that large sections of the U.S. would be subjected to heavy fallout as a result of a strategic nuclear exchange, but there is no way to predict which areas will be most affected. The requirements for radiological instrumentation will depend not only on where the fallout is but also on where the people are relative to the fallout, and this latter consideration also includes assumptions concerning evacuation from high-risk to low-risk areas prior to the attack. In any case, the basic instrumentation types that would be required include beta-gamma survey (rate) meters, dosimeters, and chargers.

2. *Requirements and Availability*

Estimates of instrumentation requirements based on the attack discussed herein and different evacuation assumptions have been made recently [3, 4]. Comparison of these requirements to the result of a survey of instruments on hand shows the following:

	Estimated Requirement (millions)	On Hands (millions)
Dosimeters	18–35	3.5
Chargers	6–10	0.5
Survey meters	6–9	0.5

The numbers available are obviously not adequate.

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* The actual value of R_1 will depend on the units in which time is expressed. It is generally expressed in hours, so the unit time for R_1 is 1 hour. Physically, it is the dose rate that would be received from a specified amount of fallout at 1 hour, although this quantity might be in transit and may not have reached the location under consideration by 1 hour after burst.

Additionally, the ranges of some of the instruments on hand may not be adequate.

E. *Countermeasures*

1. *Introduction*

The four major ways to reduce the adverse effects of fallout are: shelter, relocation, decontamination, and minimization of ingestion and inhalation (the last item is not discussed explicitly).

2. *Shelter*

The effectiveness of shelters usually is described in terms of a protection factor (PF), which is the ratio of the dose rate that would be measured 3 feet above an (imaginary) infinite smooth plane to the dose rate expected inside the shelter (accounting for surroundings as well as protection afforded by the shelter). About 20 percent of the urban population and 19 percent of the rural population of the U.S. could be afforded a PF of 1,000 or more (subways, mines, caves, and some basements) without evacuation, while about 75 percent of the urban population and 43 percent of the rural population could be afforded PF's of 100 or greater. A more complete breakdown is provided in Reference 1.

3. *Relocation*

Relocation is a preventative rather than a protective measure. If performed before an attack, large numbers of people would survive that otherwise would be killed. The precise efficacy of relocation would depend upon proper identification of areas most likely to be attacked.

After the attack, the desirability of moving would depend critically on a knowledge of the fallout fields outside the immediate vicinity, availability of transportation, and availability of shielding at the present and future locations. Coordination and communications with other locations would be necessary.

4. *Decontamination*

Decontamination would always reduce radiation exposures, but large scale decontamination to high degrees of effectiveness will require months of effort. Less effective decontamination with mass participation of the populace for short times should be considered initially.

F. *Likelihood and Consequences*

It seems generally accepted that the probability of nuclear war is greater than zero, but it becomes difficult to quantify the value further. In many cases, the estimates appear subjective, e.g. many describe nuclear war as "unthinkable" while at the same time evaluating its probability as being very high. It appears that these estimates of probability are arrived at through concern as to the consequences (i.e., the estimators appear to be evaluating risk, which is a composite of probability of occurrence and the consequences if the incident occurs). One attempt at an objective evaluation [5] using a calculating procedure, resulted in a probability of 0.03 per decade. It also reported on opinion polls that had a median of about 0.1 per decade with a wide scatter.

The consequences of a multiweapon nuclear attack would certainly be grave, but exact numbers have large uncertainties. Estimates of 20 to 160 million short term fatalities have been made, with the majority of the survivors receiving doses from >10 to a few hundred rem. Nevertheless, recovery should be possible if plans exist and are carried out to restore social order and to mitigate the economic disruption.

III Single-Weapon Attack

A. *Introduction*

A large body of information exists concerning the effects of single nuclear explosions, but there have been fewer in-depth studies related to post-attack recovery from single-weapon attacks than there have been for multiweapon attacks.

Circumstances associated with a possible single-weapon attack might include: terrorist activity (either with a "home made" weapon or one supplied by another nuclear power); covert attack by foreign nationals (possibly several widely spaced incidents); or accidental or deliberate (as a show of force during conventional or tactical nuclear war) delivery of a single strategic weapon. A terrorist weapon could range from a very primitive design to a reasonably sophisticated system.

A single-weapon attack seems likely to be conducted with a lower yield weapon than would be expected in a strategic attack. For such weapons the radiation environment would include the initial nuclear radiation as well as the residual. If the weapon is burst on or near the earth's surface, fallout would again be the primary residual radiation. Only a limited discussion of the latter is presented because of similarities to the multiweapon case.

B. *Properties of the Radiation*

1. *Sources of Radiation*

The initial radiation of concern consists of neutrons and gamma rays.* Most of the neutrons are emitted during the fission and fusion reactions during the first microsecond of the explosion. Part of the gamma rays (≤10 percent for a burst of air) are emitted simultaneously with the explosion. The remainder are produced by secondary processes (mainly reactions with

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* Alpha and beta particles that are emitted may be ignored because of their limited range in air.

atoms in the air) or de-excitation and decay of fission products.

The sources of residual radiation are the same as those discussed for a multiweapon attack.

2. *Radioisotopic Composition*

The explosion is the source of all radiation during the first few nanoseconds, and this accounts for essentially all of the neutrons. Inelastic scattering of neutrons by nitrogen in the air then becomes the primary gamma-ray source for a few microseconds when isomeric decay of fission products becomes predominant. After about 100 microseconds, gammas resulting from neutron capture in nitrogen assume greatest importence. Finally, after about 0.1 seconds, fission product decay becomes the only important source of gamma rays. Initial radiation is terminated after 1 minute according to a somewhat arbitrary definition. The residual radiation (after 1 minute) sources are the same for a single weapon as those described for a multiweapon attack.

3. *Chemical Properties*

See Section II B 3.

4. *Particle Properties*

See Section II B. 4.

If a terrorist weapon were to be burst in a basement, the debris might be expected to contain a higher fraction of large particles resulting in somewhat larger areas of high intensity radiation close to the burst point and somewhat smaller areas of lower intensity radiation.

5. *Biological Availability*

The discussion in Section II B 5 is applicable, but, in the case of a single burst in peacetime, more concern would be given to inhalation and ingestion of small quantities of radioactive materials even though retention of the majority of such particles would be short.

6. *Radiation Types*

Initial radiation: neutrons and gamma rays. Fallout: alpha, beta, gamma radiation as for multiweapon attack.

7. *Energy of the Radiation*

The gamma-ray portion of the initial radiation is more energetic, and consequently more penetrating, than are the gamma rays from fallout. The spectrum covers a wide range of energies. An effective energy of 1 MeV is used frequently for simplified calculations.

The neutrons are given off in a complex spectrum with energies ranging up to about 10 MeV for fission weapons and 14 MeV for thermonuclear weapons. The spectrum varies (hardens initially) with passage of the neutrons through air.

The discussion of Section II B 7 is applicable to the residual radiation from a single-weapon attack.

8. *Decay Characteristics*

The discussion of Section II B 8 is applicable.

C. *Areas Affected*

1. *Incident Description*

A surface burst of about 1 kt yield and an air burst of about 40 kt yield are considered herein.

2. *Extent of Radiation*

a. *Surface Burst, 1 kt:*

Initial radiation would be essentially circular about the burst point. Combined neutron and gamma doses would extend to the following approximate radii:

~500 R	~0.5 miles
~ 50 R	~0.6 miles

The fallout would extend downwind in a pattern that, for simplicity, is taken to be roughly elliptical with dimensions as follows*:

Unit-Time Dose Rate (R/hr)	Downwind Distance (Statute Miles)	Maximum Width (Statute Miles)
1,000	1.8	0.036
300	4.5	0.13
100	8.9	0.38
30	16	0.76

b. *Air Burst, 40 kt*

Initial radiation (radii):

1,000 R	~0.9 miles
100 R	~1.1 miles
10 R	~1.4 miles

The residual radiation would consist of a relatively small, generally circular area of induced activity under the burst point. The intensity would depend strongly on the chemical composition of the soil (or other material) under the burst.

3. *Population Exposure*

a. *Surface Burst, 1 kt*

In a typical U.S. city, about 8,000 persons would be in areas exposed to at least 450 R free-field initial radiation dose (about 1,200 to 1,800 of these people would be likely blast fatalities), and an additional 3,500 would be in areas exposed to between 50 R and 450 R. In addition, in a large city approximately 20,000 persons would be in areas exposed to at least a 450 R 4-

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* A 15 mph scaling wind is assumed. There would also be a relatively small circular area contaminated generally in the upwind direction.

day dose from fallout, about 170,000 persons would be in areas exposed to at least a 50 R 4-day dose, and, if the burst occurred in one of the very large metropolitan areas, up to 1 million persons would be in areas exposed to a few R.

b. *Air Burst, 40 kt*

About 40,000, 60,000, and 80,000 persons would be in areas where the free-field radiation doses would be 450, 200, and 50 rad, respectively.

C. *Dosimetry*

1. *Requirements*

The same types of instruments required for the multiweapon case would be required in the single weapon fallout areas. Additionally, alpha survey meters, air samplers, and airborne spectrometers would be required for the long term peacetime clean up operations.

2. *Availability*

Adequate instrumentation is available, but immediate availability would depend on the location. Some instrumentation probably is available in all major urban areas. Additionally, existing Department of Defense and Department of Energy resources could be called upon. The latter are discussed in Section IV, below.

D. *Countermeasures*

Shelter, relocation, and decontamination should all play a part in the recovery. If the attack should occur in a densely populated area, wounded persons and bodies of the dead would be in the area, and there might be a tendency toward panic. A strong desire to evacuate probably will exist among survivors, but, until the best route is determined, shelter may be the best course of action. Once the location of the contamination has been established, a rapid evacuation would be in order.

If started with other emergency actions, decontamination will allow the other actions to be performed more efficiently.

E. *Likelihood and Consequences*

The technology for constructing a nuclear weapon is available in unclassified sources. Although it would not be a trivial job, it would be possible for a terrorist group, an extortionist, or a country that is not a nuclear power to build a weapon. On the other hand, the technical capability to build a weapon is meaningless without the necessary special nuclear material being available.

Possible motives for building a weapon are too numerous to list, but it appears that the difficulty of obtaining the weapon grade material may be the governing factor in determining probability. Overall, the probability appears somewhat greater than that of a multiweapon attack.

The consequences of a single-weapon attack would depend strongly on the circumstances.

A surprise attack on a U.S. city certainly would cause large numbers of casualties and fatalities. A 1 kiloton surface burst could cause from 5,000 to 10,000 early fatalities (with 1,200 to 3,000 being from blast), 3,000 to 5,000 additional prompt casualties and larger numbers of delayed casualties from prompt effects. As mentioned above, large numbers of people would potentially be in areas covered by fallout. The numbers of fatalities and casualties produced by the fallout radiation would depend upon the exact scenario assumed for protection and evacuation.

A 40-kt air burst over a U.S. city could be expected to produce 50,000 to 75,000 early fatalities, with the exact number being dependent on the height-of-burst and the degree of shielding available for both blast and initial nuclear radiation.

IV Reactor Accidents

A. *Introduction*

The risk to the public posed by an accident at a reactor can be analyzed for a particular site by carefully considering the design and operating characteristics of the reactor, the local weather, the population and shelter distributions around the plant and the potential for evacuation or other measures. Such site specific evaluations have not been performed in complete detail for all operational or planned sites. The Reactor Safety Study [6] (hereafter referred to as RSS or WASH-1400), although subject to large uncertainties, provides an accident risk model that can be used to assess the potential accident risk of a plant, at least in comparison to other plants. Such evaluations are currently being performed [7].

Reactors are extremely complex systems that contain numerous subsystems to prevent the release of radioactive materials. A series of sequential failures must occur to allow release of radioactivity. Many such sequences are possible, but all of them are extremely unlikely. For the purpose of this study, two accident sequences were selected from the multitude of sequences that were examined in the RSS. One sequence involves a core melt and the other does not. These sequences, which are described later, were selected to illustrate a range of consequences. They do not represent bounds on either the consequences or the risks. In fact, it is not known whether sequences that would represent bounds have been examined. The sequences merely represent possible scenarios of accidents that could occur, and thus they provide a framework for discussion.

B. *Properties of Radionuclides from Core-Melt Accident*

1. *Sources of Radiation*

The sources of radiation are similar to those discussed in the preceeding sections: fission products, activation products, and unfissioned debris. The release would be in the form of an aerosal.

2. *Isotopic Composition*

The computer program used in the RSS to calculate the time dependent concentration of isotopes keeps track of 246 activation products, 461 fission products, and 82 transuranics. With very little sacrifice in accuracy, these numbers may be reduced for dose calculations. First, the minimum delay between the start of an accident and the release of radioactive material would be at least 0.5 hour and could be 30 hours. Most of the activity will be from daughter products of isotopes that were created long before the accident and the delay allows elimination of the few very short-lived isotopes that are present. Second, isotopes whose activity (in curies) is several orders of magnitude below the more prevalent ones may be eliminated. Finally, if the isotopes are grouped by chemical behavior, some may be eliminated because they contribute only a few percent of the dose from the group. The list may thus be reduced to 54 nuclides as shown in Table 2, which also shows the inventories and half-lives. The inventories were calculated for a 3200 MWt, three region, pressurized-water reactor (PWR), with the 3 regions having burnups of 880, 17,600, and 26,400 megawatt-days per metric ton of uranium, respectively at the time of the accident. Also shown in Table 2 are the fractions of each isotope expected to be released during the hypothetical accidents [8].

3. *Chemical Properties*

The chemical forms generally are expected to be similar to those described for a multiweapon attack. Cobalt will likely be present as the oxide or hydroxide, and the additional transuranics will probably be in the form of oxides.

In the RSS it was assumed that a large fraction of the iodines would be in elemental form. In that case, the iodine would be released in a vapor form at core temperatures, and large release fractions would be expected (c.f. Table 2). Since iodine is relatively active, it would seem likely that it would combine, in which case smaller release quantities would be expected. This hypothesis was borne out by the absence of iodine in the Three Mile Island release (a partial core melt). It has been suggested that a large fraction of the iodine would combine with cesium, which is an abundant fission product and very active chemically [9]. In the absence of other quantitative estimates, the RSS quantities are used herein, but the reader should be aware that iodine would be much less common, and that the noble gases constitute the release threat in a no-melt accident.

4. *Particle Properties*

The aerosol released during a reactor accident is expected to be a system of gases and suspended particles, both solid and liquid, that will range from 3 μm to 50 μm diameter. If the core does not melt, the material available for release will consist only of those gases that have migrated out of the fuel pellets into the plenum of the rod and whatever particulate matter that might have flaked from the surface of the pellets to become available to be swept out of the fuel rod by the gases if the cladding of the rod fails.

5. *Biological Availability (Mainly Core Melt Accident)*

Generally, the biological availability is similar to that of the weapon products, but the smaller particle sizes would cause inhalation to be a more important pathway for the reactor products. Of the fission products, only the isotopes of strontium, iodine, and cesium would represent an ingestion hazard comparable to that from inhalation. Between 20 and 95 percent of the cobalt that is taken into the gastrointestinal tract is transferred to the blood. Neptunium, americium, and curium are expected to behave in a manner similar to plutonium.

6. *Radiation Types*

As is the case for weapon explosions, alpha, beta, and gamma radiations can be generated. The gammas are of prime concern for external dose, while the alphas and betas are both of concern for internal dose.

7. *Energy of the Radiation*

Similar to that described for residual radiation from weapons.

8. *Decay Characteristics*

The radionuclides in the release will include both young and old fission products and neutron-activation products, with a much higher proportion of longer half-lived isotopes than is the case for weapon debris. Isotopes with very short half-lives would be important in relatively small quantities if present, but the delay between occurrence of the accident (with resultant cessation of fission) and the release allows these isotopes to decay away. Considering these factors and the gamma energies of the radiations, only the following isotopes need be considered for the external dose from deposited contamination: Co-58, Co-60, Nb-95, Zr-95, Ru-103, Ru-106, I-131, Cs-134, Cs-136, and Cs-137. For the first few weeks, the iodine is most important; next, the isotopes of ruthenium will dominate the dose up to about a year; thereafter, cesium is dominant.* During passage of the cloud, those isotopes with half-lives shorter than about 8 days are most important (see Table 2).

C. *Areas Affected*

1. *Description of Accident*

a. *General*

Release of significant quantities of radioactive nuclides beyond the reactor enclosure usually requires overheating the core. This overheating can result from a failure in the cooling system or as the result of a transient increase in power beyond the capability of the cooling system to counter. If a temperature on the order of 2,200°F is reached, the zirconium cladding on the fuel rods will react with the surrounding water to form zirconium oxide with a release of hydrogen. The zirconium oxide is brittle, and eventually it will fail. If the temperature rises above 4,800°F, the fuel pellets will melt.

b. *Core Melt Accident*

This release category can be characterized by a sequence of malfunctions leading to a core meltdown followed by a steam explosion on contact of molten fuel with the residual water in the reactor vessel. The containment spray and heat removal systems are also assumed to have failed and, therefore, the containment could be at a pressure above ambient at the time of the steam explosion. It is assumed that the steam explosion would rupture the upper portion of the reactor vessel. In the extremely remote probability that the containment vessel were also breached (from forces within, or a coincidental force, like a meteor impact, from without), a substantial amount of radioactivity might be released from the containment in a puff over a period of about 10 minutes. Due to the sweeping action of gases generated during containment-vessel meltthrough, the release of radioactive materials would continue at a relatively low rate thereafter. Because the containment would contain hot pressurized gases at the time of failure, a relatively high release rate of sensible energy from the containment could be associated with this category. This category also includes such accident sequences as a failure of containment through rupture of cooling or feedwater pipes permitting release from containment. In these sequences, the rate of energy release would be lower, although still relatively high.

c. *No Core Melt*

This category approximates a pressurized water reactor (PWR) design basis accident (large pipe break), except that the containment would fail to isolate properly on demand. The other engineered safeguards are assumed to function properly. The core would not melt. Most of the release would occur in the 0.5-hour period during which containment pressure would be above ambient. Because containment sprays would operate and core melting would not occur, the energy release rate would also be low.

2. *Extent of Contamination for Core Melt Case*

The contaminated area could cover a sector roughly 22.5 degrees on each side of the center line in the direction of the effective wind to a distance of about 200 miles. Potentially fatal doses (beginning at about 300 rem), would be limited to about 10 miles downwind from a severe accident release. Exposure up to 50 rem could occur as far as 50 miles, and latent cancer fatalities might occur as far as 200 miles from a severe accident.

3. *Population Exposure*

The population that could be exposed depends upon the specific site. Ranges in population are:†

360° Around Site

	Low		High	
Radius (miles)	Site	Population (thousands)	Site	Population (thousands)
10	Sundesert	0	Indian Point	218
30	Sundesert	0.09	Indian Point	3,985
50	Sundesert	7.8	Indian Point	14,471

Highest 22-1/2° Sector

Radius (miles)	Site	Population (thousands)
10	Zion	65
30	Indian Point	1,800
50	Indian Point	8,000

Among the 111 existing or planned reactors almost any number is possible up to the Indian Point maximum within 50 miles, depending on the site and weather.

D. *Dosimetry*

Interim guidance has been published [10] and is being used by FEMA and NRC staff in their reviews of emergency plans and preparedness of state and local governmental and facility operators. After public comments are received, NRC will establish a

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* A rough estimate of the dose-rate decay may be obtained by assuming that the dose-rate decay is proportional to the heat loss. For infinite irradiation, the decay heat may be calculated from

$$P/Po = 0.130t^{-0.283}, \quad 150 < t < 4 \times 10^6 \text{ sec},$$

where P/Po is the fraction of operating power and t is the decay time in seconds. If the dose-rate decay is proportional to the heat and the dose rate, $\dot{D}_1$, is known for some time, t_1, then for any other time, t_2:

$$\frac{\dot{D}_2}{\dot{D}_1} = \left(\frac{t_2}{t_1}\right)^{-0.283}$$

where t may be in any units. This equation has not been substantiated empirically or theoretically. Alpha decay will affect the heat significantly without affecting external dose. Nevertheless, the proportionality may be reasonably close.

† Based on 1970 census.

Table 2
RADIONUCLIDES RELEASED AT THE TIME OF THE HYPOTHETICAL ACCIDENTS[*]

Nuclide	Half-Life (days)	Radiation Type(s)	Core Inventory (Ci X 10^{-8})	Fraction Released Core Melt	Fraction Released No Melt
Co-58	71.0	β^+, γ	0.0078	0.4	0
Co-60	1,920.	β, γ	0.0029	0.4	0
Kr-85	3,950.	β, γ	0.0056	0.9	2 X 10^{-3}
Kr-85m	0.138	β, γ	0.24	0.9	2 X 10^{-3}
Kr-87	0.0528	β, γ	0.47	0.9	2 X 10^{-3}
Kr-88	0.117	β, γ	0.68	0.9	2 X 10^{-3}
Rb-86	18.7	β, γ	0.00026	0.4	5 X 10^{-4}
Sr-89	52.1	β, (γ)[†]	0.94	0.05	1 X 10^{-8}
Sr-90	11,030.	β	0.037	0.05	1 X 10^{-8}
Sr-91	0.403	β, γ	1.1	0.05	1 X 10^{-8}
Y -90	2.67	β, (γ)[†]	0.039	3 X 10^{-3}	0
Y -91	59.0	β, (γ)[†]	1.2	3 X 10^{-3}	0
Zr-95	65.2	β, γ	1.5	3 X 10^{-3}	0
Zr-97	0.71	β, γ	1.5	3 X 10^{-3}	0
Nb-95	35.0	β, γ	1.5	3 X 10^{-3}	0
Mo-99	2.8	β, γ	1.6	0.4	0
Tc-99m	0.25	γ	1.4	0.4	0
Ru-103	39.5	β, γ	1.1	0.4	0
Ru-105	0.185	β, γ	0.72	0.4	0
Ru-106	366.	β	0.25	0.4	0
Rh-105	1.5	β, γ	0.49	0.4	0
Te-127	0.391	β, γ	0.059	0.4	1 X 10^{-6}
Te-127m	109.	β, γ	0.011	0.4	1 X 10^{-6}
Te-129	0.048	β, γ	0.31	0.4	1 X 10^{-6}
Te-129m	34.	β, γ	0.053	0.4	1 X 10^{-6}
Te-131m	1.25	β, γ	0.13	0.4	1 X 10^{-6}
Te-132	3.25	β, γ	1.2	0.4	1 X 10^{-6}
Sb-127	3.88	β, γ	0.061	0.4	1 X 10^{-6}
Sb-129	0.179	β, γ	0.33	0.4	1 X 10^{-6}
I -131	8.05	β, γ	0.85	0.7	1 X 10^{-4}
I -132	0.0958	β, γ	1.2	0.7	1 X 10^{-4}
I -133	0.875	β, γ	1.7	0.7	1 X 10^{-4}
I -134	0.0366	β, γ	1.9	0.7	1 X 10^{-4}
I -135	0.280	β, γ	1.5	0.7	1 X 10^{-4}
Xe-133	5.28	β, γ	1.7	0.9	2 X 10^{-3}
Xe-135	0.384	β, γ	0.34	0.9	2 X 10^{-3}
Cs-134	750.	β, γ	0.075	0.4	5 X 10^{-4}
Cs-136	13.0	β, γ	0.030	0.4	5 X 10^{-4}
Cs-137	11,000.	β, γ	0.047	0.4	5 X 10^{-4}
Ba-140	12.8	β, γ	1.6	0.05	1 X 10^{-8}
La-140	1.67	β, γ	1.6	3 X 10^{-3}	0
Ce-141	32.3	β, γ	1.5	3 X 10^{-3}	0
Ce-143	1.38	β, γ	1.3	3 X 10^{-3}	0
Ce-144	284.	β, γ	0.85	3 X 10^{-3}	0
Pr-143	13.7	β	1.3	3 X 10^{-3}	0
Nd-147	11.1	β, γ	0.60	3 X 10^{-3}	0
Np-239	2.35	β, γ	16.4	3 X 10^{-3}	0
Pu-238	32,500.	α (γ),[†] SF[‡]	0.00057	3 X 10^{-3}	0
Pu-239	8.9 X 10^{6}	α, SF[‡]	0.00021	3 X 10^{-3}	0
Pu-240	2.4 X 10^{6}	α, (γ),[†] SF[‡]	0.00021	3 X 10^{-3}	0
Pu-241	5,350.	β, γ, (α)[†]	0.034	3 X 10^{-3}	0
Am-241	1.5 X 10^{5}	α, γ	0.000017	3 X 10^{-3}	0
Cm-242	163.	α, (γ),[†] SF[‡]	0.0050	3 X 10^{-3}	0
Cm-244	6,630.	α, (γ),[†] SF[‡]	0.00023	3 X 10^{-3}	0

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[*] Compiled from data in Reference 8.

[†] Parenthesis indicates weak intensity.

[‡] SF = Spontaneous Fission.

Note: See page 7, Dr. Spencer's paper, for explanation of why several nuclides in Table 2 are identified by a bullet. (Ed.)

schedule for implementing the requirements for staffing and equipment.

The interim guidance requires the facility operators to provide for activating and staffing an emergency operations center. The equipment shall include: geophysical phenomena monitors (meteorological, hydrologic, and seismic); radiological monitors (process, area, emergency, effluent, and portable); process monitors (reactor coolant system pressure and temperature, containment pressure and temperature, liquid levels, flow rates, status or lineup of equipment components); and fire and combustion products detectors.

The guidance further requires the operators to make provision for offsite monitoring equipment, including: geophysical phenomena; radiological (ratemeters and sampling devices); and laboratory facilities (either fixed or mobile).

The equipment listed above adequately covers immediate emergency requirements as to type. Quantities, either planned or on hand are unknown.

In addition to the equipment listed above, it would be desirable to have a capability for aerial surveys, including spectral measurement and analysis, to rapidly identify the composition of the discharges. The Department of Energy has such a capability, and it was put to use at Three Mile Island [11]. The Department of Energy Laboratories also have analytical and measurement capabilities that can be made available rapidly under the Interagency Radiological Assistance Plan (IRAP).

E. *Countermeasures*

Homes with windows and doors closed can reduce the inhalation hazard for occupants while the plume from the discharge is passing. Since the discharge will take place over an extended time compared to an explosion, early warning could make such precautions fruitful.

If monitoring shows a release capable of producing serious injury, evacuation may be undertaken. Generally, this should involve only personnel within about a 10 mile radius.

The most serious hazard from ingestion is likely to come from radioiodine. Potassium iodide may be used as a thyroid blocking agent, if supplies are available for early dispersal.

Decontamination and food control can reduce exposures after the accident. Control of milk to avoid iodine ingestion may be necessary to a radius of hundreds of miles.

F. *Likelihood and Consequences*

The RSS [6] arrived at a probability of an accident involving a core melt of 5×10^{-5} (1 in 20,000) per reactor per year. This is a planning number intended for general use where no better quantity exists. Actually the probability depends on the specific reactor design. Recent analyses of 8 designs shows estimates from 2×10^{-4} down to 1×10^{-5} per reactor per year [7]. Nevertheless, reactor accidents represent very low risks compared to most man-caused fatal accident types.

The consequences will depend on the site of the accident as well as the magnitude of the release. In general, less than 10 percent of the accidents involving core melt will result in lethal doses offsite (i.e. more than 90 percent of the core melts will not produce lethal doses offsite), and no early fatalities are expected if there is no core melt.

The Surry reactor would be expected to produce one or more acute fatalities at the rate of 3.2×10^{-6} per year if located at Indian Point, but at the rate of only 1.5×10^{-7} per year if located at Diablo Canyon [7]. Integrating the probability-fatality relations for the Surry reactor at 6 locations results in expected consequences ranging from 1.6×10^{-9} early fatalities per year at Diablo Canyon to 6.1×10^{-3} early fatalities per year at Indian Point (Indian Point reactor at its own site is expected to be about 2.2×10^{-4} early fatalities per year).

Reactor accidents are low probability events, but consequences may be high. If there is one fatality there is a likelihood of several hundred, i.e. the probabilities for one and for several hundred are almost identical. Nevertheless, reactor accidents represent low risks compared to most man-caused accidents.

V Transportation Accidents-Spent Fuel

A. *Introduction*

At present, almost all spent fuel is being stored at the reactor sites and no transportation is being performed. Should shipping commence, there will still be a holding period of at least 120 to 180 days after removal from the core. Shipments will be in specially designed and licensed casks. The casks consist of concentric stainless steel cylinders containing the fuel assemblies, lead shielding, neutron absorber, and coolant. Casks designed for truck transport range in capability from 1 to 3 PWR assemblies and 2 to 7 BWR assemblies with loaded weights ranging from 23 to 36 metric tons. The casks have impact limiters on the ends and are designed to survive 30 mph* impacts [12]. A testing program precedes licensing. Although the shipping casks are licensed for as little as 120 to 180 days of cooling, it is expected that shipments seldom will be made in less than about a year of cooling.

B. *Properties of Radionuclides*

The radionuclides that might be released from spent fuel are those that might be released from a reactor core accident (see Table 2), i.e., they are the nuclides found inside the fuel rods, including iodine. The main difference is the age, which eliminates the shorter half-life isotopes. The discussion of Section IV B is generally applicable concerning all properties.

If there is an accident involving cracking of the case or penetration of the case by a missile the gaseous nuclides present in the open space of the rods will

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* Based on vertical drop tests of the cask on a solid concrete slab, where the cask velocity reaches 30 mph.

escape and will carry with them particles that may have flaked off. The release generally will have chemical and physical properties similar to those described for reactors. Yttrium-90 (half-life = 2.67 days) is the shortest half-life expected to be significant (see Table 2).

If an intact fuel assembly should somehow be ejected from the shipping cask, the unshielded assembly would represent essentially a point source of 1.8×10^6 curies. This has been taken as a very low-credibility bounding event for analysis [12]. If that should occur, the dose-distance relation is:

$$\dot{D} = 8.2 \times 10^5 \frac{e^{-3.5 \times 10^{-3R}}}{R^2}$$

where $\dot{D}$ is the dose rate in rem/hr, and R is the distance in meters.* Such an accident would also be expected to release more activity in the plume as a result of damage to the ejected assembly.

C. *Areas Affected*

Calculations were performed [12] for integrated exposures of persons exposed to the plume directly, and then exposed for 1 day to the deposited contamination. If no fuel rods are ejected but a fire occurs after the impact, the estimated exposures from the airborne release are:

Distance (feet)	Lower limit (rem)	Upper limit (rem)
100	2.9	410
1,000	2.1	285
10,000	0.11	15

The plume would be expected to expand downwind into about a 15° sector.

D. *Dosimetry*

The same types of dosimetry required for reactor accidents would be required for vehicle accidents.

The author has found no reference to a requirement for instrumentation to be available on the vehicle, so it is assumed that instruments would have to be brought to the scene. Some action probably would have to be taken to mitigate exposure to personnel at the scene prior to arrival of instruments.

E. *Countermeasures*

Temporary evacuation of a buffer area would appear to be the immediate measure to be taken. Otherwise, countermeasures are similar to reactor accidents.

F. *Likelihood and Consequences*

The probability of a truck accident is about one per million vehicle miles. It has been estimated that only one in 100 of these accidents will be severe enough to damage the casks [13]. The total vehicle miles (rail plus truck) are estimated to be about 90,000 per year, so the estimated probability for a severe accident is 0.01 per decade. The severe accidents are assumed herein to result in airborne releases. The probability of a fuel assembly being ejected is thought to be too low to estimate.

It is likely that any severe accident would take place in a sparsely settled environment, and exposure of personnel (other than the drivers involved) is likely to be minimal.*

VI Transportation Accidents—Weapons

A. *Introduction*

This section considers transportation of weapons by aircraft. The accident might involve crash of the aircraft with a subsequent fire or an accidental dropping of the weapon. In either case, the high explosive in the weapon may or may not detonate. In no case will there be a nuclear explosion.

Table 1 summarizes the environmental factors for this type of accident in sufficient detail for this summary report. Therefore, only very brief amplification is provided below. Reference 1 should be contacted for more detail.

B. *Discussion*

There will be no external hazard from the unfissioned weapon material. The only radiation hazard would result from inhalation or ingestion of plutonium. Uranium taken internally represents a heavy-metal poison hazard in quantities less than those required to be a radiation hazard.

Less than 10^{-4} of the plutonium eaten by man is absorbed from the intestine. Inhalation is a more probable route of deposition, but once the cloud has passed, inhalation requires that the plutonium be resuspended. This is an inefficient process.

"Soluble" plutonium may be cleared from the lung within a year or so and will be translocated primarily to bone and the liver. "Insoluble" plutonium will be retained much longer in the lung and will be translocated principally to lymph nodes. Plutonium dispersed in a weapon accident is expected to be in the form of insoluble oxides.

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* Assuming fuel assembly irradiated for 33,000 MWD/MTU followed by 180 days of cooling.

* The main problem, which could involve a radiation hazard to a clean-up crew, would result if the cooling system surrounding the cask is interrupted.

Two accidents of this type are recorded. These are described in Reference 1 and in more detail in References 14 and 15. The first occurred near Polomares, Spain on January 17, 1966. A B-52 collided in flight with a tanker during a refueling operation, and 4 weapons were dropped. One weapon was found on the beach undamaged, and one was recovered intact from the sea at a much later date. The other 2 weapons resulted in high explosive detonations on impact with the earth. The resulting contamination covered about 650 acres with a concentration of about 5 $\mu g/m^2$ or more.

The second accident occurred near Thule, Greenland on January 21, 1968. A B-52 crashed on an ice floe just off the coast. Snow was falling at the time of the accident, and the precipitation increased after the accident. Most of the plutonium sank with the aircraft debris, and the rest was trapped under the snow and froze into the ice. This accident was notable in being the first "field" use of the LRL Field Instrument for Detection of Low Energy Radiation (FIDLER) survey meters. This instrument detects the weak 60 keV gamma from Americium-241, and allows a much more efficient survey of the plutonium contamination to be conducted than was possible previously with alpha survey meters.

Countermeasures after such an accident include evacuation initially, followed by decontamination. The latter should include removal and destruction of all vegetation and plowing under or removing contaminated soil. About 5,500 barrels (1,500 yd^3) of soil that were contaminated at levels equal to or greater than about 460 $\mu g/m^2$ were shipped from Spain to the U.S. for disposal.

The worst consequence of such an accident is likely to be a partial denial of the use of a relatively small area.

VII Transoceanic Fallout

A. *Introduction*

This category of incident is also likely to cause only low-level consequences if countermeasures are taken. Table 1 summarizes the environmental factors reasonably well, so only a brief discussion is provided for amplification.

B. *Discussion*

As mentioned in Section II, delayed fallout is that which falls after 24 hours. It results from that portion of the weapon debris that is attached to small particles (less than about 50 μm) from a surface burst, and essentially all of the debris from an air burst. The delayed fallout may be divided further into tropospheric and stratospheric, depending on whether or not the fireball carries the particles through the tropopause. Those particles that are deposited above the tropopause will be dispersed worldwide and will gradually migrate down to earth over a period of years. Those particles that are deposited below the tropopause will form a continuous stream stretching from the limit of the local fallout around the world at about the same latitude as that at which they are injected. This latter is the fallout with which we are concerned here.

The effects on the U.S. resulting from fallout from a Sino-Soviet war have been examined [16]. Tactical weapons with yields of a few tens of kilotons would create the greatest hazard to the U.S. per weapon exploded. Higher yields would deposit a larger proportion of their activity in the stratosphere, and lower yields would deposit a larger fraction of their activity closer to the burst. Furthermore, air burst tactical weapons will produce more of this type of fallout than will surface bursts.

The radioactive cloud from a burst over China might arrive over the U.S. within about five days. The cloud will then drift across the country, circle the globe and return. This process will continue over a period of weeks, and with each crossing of the U.S., some fallout will be deposited. The quantity of fallout deposited will be increased significantly each time that rain occurs through the radioactive cloud.

The main potential hazard from transoceanic fallout during the first few weeks arises from the ingestion of I-131, which has a half-life of eight days. Like all isotopes of iodine, I-131 tends to concentrate in the thyroid gland. The I-131 can be ingested in water, milk, meat, grain, and vegetables, or on leafy vegetables eaten raw; however, it has been estimated that 80 percent of the dose to the thyroid would result from ingestion of contaminated milk. [16] It has also been noted that the thyroid of infants with the same daily intake of contaminated milk would receive about 10 times the adult thyroid dose. Moreover, the thyroid of an adult is much more resistant to damage by radiation than is that of a young child. Thus, the most serious consequence of transoceanic fallout is likely to be a significant increase in thyroid cancer cases (not deaths) among the young, and particularly among infants.

The production of contaminated milk could be avoided by removing dairy cows from pasture prior to fallout arrival and providing them with clean food and water. Arrival of fallout is likely to be predictable since the radioactive clouds of foreign tests are routinely tracked over the Pacific ocean. If it is not possible to remove the cows from pasture or if they must be returned to a contaminated pasture, fresh milk substitutes could be used until acceptable fresh milk is available. Much of the contaminated milk could be processed for later distribution and consumption after the I-131 activity has decayed away. It may be necessary to limit or divert distribution of milk so that the needs of the very young in the affected communities are satisfied.

If precautions are taken with regard to consumption of contaminated milk, the overall consequences of this type of incident are not likely to be great.

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APPENDIX B

Civil Defense and Nuclear Energy*

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Most of the world's democracies, with the exception of France and Japan, are experiencing a nuclear moratorium. The United States has ordered no new nuclear power plants for about three years; in Austria the Zwentendorf reactor was completed but was not turned on; Sweden has decided to reject nuclear power after the year 2000—the present 12 reactors would be built and operated, but after that, no more.

This rejection of nuclear energy has been catalyzed by the articulate and influential energy radicals in the Western world. They oppose nuclear power because it is a centralized, electrical form of energy, and because in their view it is dangerous and leads to proliferation of nuclear weapons and therefore makes nuclear war more likely. Insofar as they think about nuclear war, they seem to sublimate and transform their concern about nuclear war into an opposition to nuclear energy. Their strategic stance tends toward the conventional wisdom: an offensive confrontation is regarded as more acceptable than a defensive confrontation. For reasons that are not entirely clear to me, this group strongly opposes civil defense or, more generally, defensive systems of any kind. Instead, they accept the principle of mutually assured destruction (MAD).

I shall try to argue the opposing positions on both nuclear war and nuclear power: namely, that defense (including civil defense), not offense, should be the basis of a stable world order; and that nuclear power should be used because it makes war less likely, not more likely.

The doctrine of Mutually Assured Destruction has dominated the strategic argument in this country for the last 30 years. As a corollary, offensive weapons are regarded as being safer than defensive weapons. Indeed, in the first round of the SALT talks, severe limits were placed on ABM deployment. MAD (an acronymn coined by the late Donald G. Brennan) has been so ingrained in our strategic thinking that anyone who tries to offer the opposite viewpoint—that defensive weapons kill no one and are therefore "safer" than offensive ones—is regarded with disdain by the strategic cognescenti.

About 15 years ago I gave a talk entitled "Let Us Prepare for Peace" at the Atoms for Peace award ceremonies. I argued that true disarmament would be possible only if nations saw no threat from small clandestine weapons that escaped an inspection system. This would be the case only if nations had strong defensive systems that could deal with such sneak attacks. Though these views were not well received at the time, I continue to believe, and preach, the obvious: that defensive systems are less threatening than offensive systems: 100 million Americans can't be killed with Russian ABM's or civil defense, nor can we kill 100 million Russians with an ABM or civil defense system.

This heresy in strategic doctrine is now being discussed, among strategic thinkers, as much as anything because the MAD posture is becoming untenable. As MX's follow MIRV's, we witness an unending escalation of the level required for "stability."

Among those who espouse a defensive posture is Freeman Dyson, the physicist. In his autobiography, *Discovering the Universe*, Dyson talks about his experience as an operations analyst in the Royal Air Force during World War II. Though he was on the English side, he gradually acquired more and more sympathy for the German fighter pilots who were trying to prevent the Americans and the British from bombing the German cities. As he puts it, defense is morally superior to offense: it is the technologists' task to make it feasible. Dyson therefore argues for converting the current offensive confrontation into a defensive confrontation. Professor Rosen, of the Harvard Center for International Studies, on public radio just a couple of weeks ago has expressed these same views. And I myself have had private conversations with strategic thinkers of the MAD school who concede that if defensive systems could be made sufficiently reliable, a defensively oriented world would be safer than an offensively oriented one. Escalation of defense is not nearly as threatening as is escalation of offense.

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* Presented as banquet address, National Council on Radiation Protection and Measurements symposium on "The Control of Exposure from Ionizing Radiation in the Event of Accident or Attack," Reston, Virginia, April 27, 1981.

Arms agreements should limit offensive weapons, not defensive ones, rather than the opposite, as is now the case.

The ultimate issue is not how many people are going to be killed in a nuclear war: it is how can we both maintain our freedoms and avoid nuclear war. Reducing the likelihood of nuclear war is a far more important issue than reducing the magnitude of a nuclear war. A defensively oriented world is intrinsically less threatening than an offensively oriented world; a defensively oriented world is less likely to slip into inadvertent nuclear war than is an offensively oriented one.

I shall argue that a strong commitment to nuclear power is also likely to reduce the probability of large-scale war, and therefore reduce the probability of nuclear war. All of us are aware of the opposite claim—that a world committed to nuclear power is a proliferated world; and a proliferated world is much less safe than an unproliferated one.

We nuclear people have always insisted that nuclear power is a possibly sufficient condition for proliferation, but it is by no means a necessary condition. For example, according to the newspapers, Pakistan is building a reprocessing plant. It can make bombs from plutonium made either in its power reactor or from its research reactor. Its capacity to make a bomb there does not depend on its having nuclear power, especially since Pakistan is going ahead with centrifuge development, a more direct way to nuclear weapons than is a nuclear power plant.

Nuclear power is an instrument of peace because it reduces pressure on oil. The energy crisis is primarily a crisis of liquid fuels. Insofar as nuclear power can replace oil, it helps stabilize the world order.

The world today uses about 60 million barrels of oil per day; of that, about 18 million barrels per day came through the Straits of Hormuz before the Iran/Iraq war. A nuclear reactor of 1000 megawatts electric output uses the equivalent of about 25,000 barrels of residual oil per day. If the world had 1000 reactors operating now, the primary energy supplied by uranium to those 1000 reactors would exceed the 18 million barrels of oil per day that go through the Straits of Hormuz. To be sure, the substitution is not direct, since what would be displaced is residual oil, not gasoline or other higher distillates. But with an expenditure of about $10–15 thousand per daily barrel of capital equipment, refineries could convert the residual oil into higher distillates. So to speak, residual oil, made available by conversion from oil-fired to nuclear power plants, is the best feedstock for a synthetic fuel plant. To make high distillates from coal requires an expenditure of about $100,000 per daily barrel. To make high distillates from residual oil takes only about one-tenth as much.

One country, France, is following this common-sense approach. By 1990, France will be deriving 30 percent of its primary energy from nuclear power. It will be cutting back on its oil imports at that time by about 30 million tons of oil per year. (Because it will be producing 40 percent of its total energy from non-fossil sources by 1990, France will be the only country in the world that in 1990 will be throwing less carbon dioxide into the atmosphere than it is throwing into the atmosphere today. And if all the Organization for Economic Cooperation and Development countries moved to nuclear as aggressively as France is doing, then concern over carbon dioxide would be pushed some 50 years farther into the future.)

This simple-minded argument cannot be ignored: substitution of nuclear energy for oil reduces the pressure on oil and therefore reduces the political pressures that lead first to political instability, then to war, and possibly eventually to nuclear war. We forget that the immediate cause of the Japanese attack on Pearl Harbor was the decision by the United States to prevent Japan from moving into Indonesia to get oil. The Japanese entry into World War II demonstrated how oil can trigger a world conflagration.

I have argued that both defensive systems (including civil defense) and nuclear energy, if deployed widely, would tend to reduce the probability of nuclear war. I now speculate on whether nuclear energy and concerns over nuclear energy can be an avenue to a stronger civil defense; and conversely, whether civil defense might help remove obstacles to the deployment of nuclear energy.

First, to what degree has the concern about nuclear energy generated by Three Mile Island excited interest in civil defense? Before Three Mile Island, no one in the utility industry took seriously the possibility of a reactor accident. After Three Mile Island this possibility became reality. In the wake of Three Mile Island, people seem to be much readier to do many of the same things that they would have to do were they to take civil defense more seriously. Thus at the recently commissioned Sequoyah reactor, TVA has conducted a full-scale practice alert. Had Three Mile Island not happened, I suspect the public would not have cooperated in the exercise. I sense, though I cannot prove, that acceptance by the public of the possibility of a radiation accident has encouraged a climate of acceptance for civil defense.

In reciprocal fashion, familiarity with radiation resulting from successful civil defense ought to make nuclear energy more acceptable. Consider the hysterical overestimation of the possible radiobiological effects from a meltdown in a nuclear reactor demonstrated at Three Mile Island. This hysteria stems from the public's inability to distinguish between a microcurie and a megacurie. Because people have no sense of the magnitudes, their fears are out of all proportion to the actual danger. They take their frustration out in a rejection of nuclear energy.

A civil defense system such as Switzerland is striving toward would eventually teach people about radiation. Everyone will know the difference between 100 millirads and 100 rads; they will understand about geiger counters; and a public that understands radiation will not exhibit hysterical fear of radiation. Such a public will find nuclear energy more acceptable than a public that does not understand radiation. To summarize, insofar as civil defense helps educate the public about radiation, it should make nuclear power more acceptable. Conversely, insofar as nuclear power heightens the public's awareness of the possibility of radiation mischance, it should make civil defense more acceptable.

I don't know whether nuclear energy, which is now in a state of moratorium, will get started again. I doubt that there will be another nuclear power plant built in the United States for at least a half-dozen years. I do believe that we won't have a second nuclear era unless and until the public acquires a more reasonable attitude towards the danger of low levels of radiation. Though experience with civil defense would bring to the public a better understanding of the possible hazards of low levels of radiation, and therefore more acceptance of nuclear power, we cannot wait simply on civil defense to be the boat on which nuclear energy will catch a free ride.

That people will eventually acquire more sensible attitudes towards low levels of radiation is suggested by an analogy, pointed out by William Clark, between our fear of very low levels of radiation insult and of witches. In the fifteenth and sixteenth centuries, people knew that their children were dying and their cattle were getting sick because witches were casting spells on them. During these centuries no fewer than 500,000 witches were burned at the stake. Since witches were causing the trouble, if you burn the witches, then the trouble will disappear. Of course, one could never be really sure that the witches were causing the trouble. Indeed, though many witches were killed, the troubles remained. The answer was not to stop killing the witches—the answer was: kill more witches.

The analogy between our present environmental hysteria and witch hunting is too close to be taken lightly. There are many in our scientific community who know that cancer is caused by low levels of radiation or other environmental insult, and that therefore one has to clean up: and if so much clean-up does not reduce the cancer mortality, you haven't cleaned up enough. This, of course, is an unending regress. Just as in the fifteenth and sixteenth centuries there was an institution, the Inquisition, that was in the business of extirpating the cause of the difficulty, so today we have innumerable bodies, both public and in the public interest, who have a vested interest in pursuing the unending task of clean-up.

I want to end on a happy note. The Inquisitor of the south of Spain, Alonzo Frias, in 1610 decided that he ought to appoint a committee (he didn't give it a number like you do here at NCRP) to examine the connection between witches and all these bad things that were happening. The committee could find no real correlation between the number of witches that were burned and the number of children that died or the number of cattle that got sick. So the Inquisitor decided to make illegal the use of torture to extract a confession from a witch. As a result, the witch-burning business fell precipitously.

I don't know whether the modern witch—low level radiation and the hysteria that is exhibited about nuclear energy—will be resolved soon enough for nuclear energy to play a proper part in avoiding the oil confrontation. After all, it took 200 years for the Inquisition to run its course on witches. I only hope that our attitude towards nuclear energy will become more sensible long before 200 years have gone by. The possible alternative—nuclear war sparked by competition for dwindling oil—is far too horrible to accept, whether or not we have civil defense.